AD-A042 710 CORPS OF ENGINEERS SAUSALITO CALIF SOUTH PACIFIC DIV LAB F/G 8/7
SHEAR STRENGTH OF ROCKFILL, PHYSICAL PROPERTIES. ENGINEERING ST--ETC(U)
OCT 75 M W COHEN, D D LESLIE

UNCLASSIFIED NL

1 OF 2
AD
A042 710

DISTRIBUTION STATEMENT A

Approved for public release;
Distribution Unlimited

SHEAR STRENGTH OF ROCK FILL

PHYSICAL PROPERTIES

ENGINEERING STUDY NO. 526

October 1975

DEPARTMENT OF THE ARMY
SOUTH PACIFIC DIVISION, CORPS OF ENGINEERS
LABORATORY
SAUSALITO, CALIFORNIA 94965

THE CONTENTS OF THE REPORT ARE NOT TO BE USED FOR ADVERTISING, PUBLICATION, OR PROMOTIONAL PURPOSES. CITATION OF TRADE NAMES DOES NOT CONSTITUTE AN OFFICIAL ENDORSEMENT OR APPROVAL OF THE USE OF SUCH COMMERCIAL PRODUCTS

PREFACE

The investigation reported herein is part of a continuing investigation for the Office, Chief of Engineers (OCE), under Item ES 526 of the Soil Mechanics Engineering Studies Program. It was authorized by OCE by multiple letter ENGCW-EC, 1 November 1962, "Civil Works Investigation - FY 1963". Since July 1973, funding of this study has been from WES and the study designation has been changed to CWIS No. 31202 - Shear Strength of Rockfill.

The study was performed under the general direction of Mr. R. A. Barron, former Chief, Soils Branch, OCE, Mr. A. L. O'Neill, Chief, Geology, Soils and Materials Branch, SPD, and Mr. D. D. Leslie, former Chief.

The testing and preparation of the report were performed under the direction of Mr. M. W. Cohen under the supervision of Mr. E. A. Hein, Chief, Soils Section, and direction of Mr. J. E. Ott, former Director, and Mr. R. A. Chisholm, Director, Division Laboratory. Mr. Leslie provided technical review of the report.

PREVIOUS REPORTS ON

COARSE MATERIALS

Shear Strength of Rock Fill, Alluvial Gravel, Engineering Study 526	March 1972
Shear Strength of Rock Fill, Engineering Study 526. Crushed Basalt and Metavolcanic Straight-Line Gradations	December 1967
"R" Type Triaxial Compression Tests on Gravel, Civil Works Investigation No. 521-C	November 1963
Triaxial Shear Tests on Sands and Gravels. Civil Works Investigation, No. 521-B, Combined Report	September 1961
Effect of Rock Sizes on Shear Strength, Civil Works Investigation No. 488, Interim Report	February 1956
Shear Strength of Gravelly Soils, Civil Works Investigation No. 512	March 1953

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF PLATES

APPENDIX A

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	25.4	millimeters
feet	30.48	centimeters
pounds per square inch	0.070307	kilograms per square centimeter
tons per square foot	2.4412	kilograms per square meter
pounds per cubic foot	16.0185	kilograms per cubic meter
gallons	3.78533	liters

ENGINEERING STUDY 526

SHEAR STRENGTH OF ROCKFILL

PHYSICAL PROPERTIES

INTRODUCTION

1. Several years ago, the Corps of Engineers departed drastically from the then current practice of constructing rockfill dams by dumping random rock sizes, often weighing as much as several tons, in lifts up to 50 feet thick. Instead, the Corps adopted the procedure of limiting particle sizes to 24 to 36 inches and compacting in layers of equal thickness. Also, where only assumptions of strength, permeability and consolidation had been made, equipment and methods were developed to determine these parameters in the laboratory.

2. This is the third report of a laboratory study carried on since 1963 to investigate the shear strength properties of coarse fill materials. Previous reports of Engineering Study 526 dealt with the influence of gradation, confining pressure and relative density on the shear strength of rockfill and gravelly materials using artificial gradations. It was found that shear strength increased with increasing coefficient of uniformity and relative density, and decreased with increasing confining pressure. One of the most important findings was that modeled gradations would give reasonably identical results, making it possible to predict the shear strength of gradations as placed in the dam.

3. In this study, shear and consolidation characteristics have been correlated with physical properties. Originally, the intent was to study only the relation of physical properties to shear strength, but, since consolidation is an equally important consideration in the performance

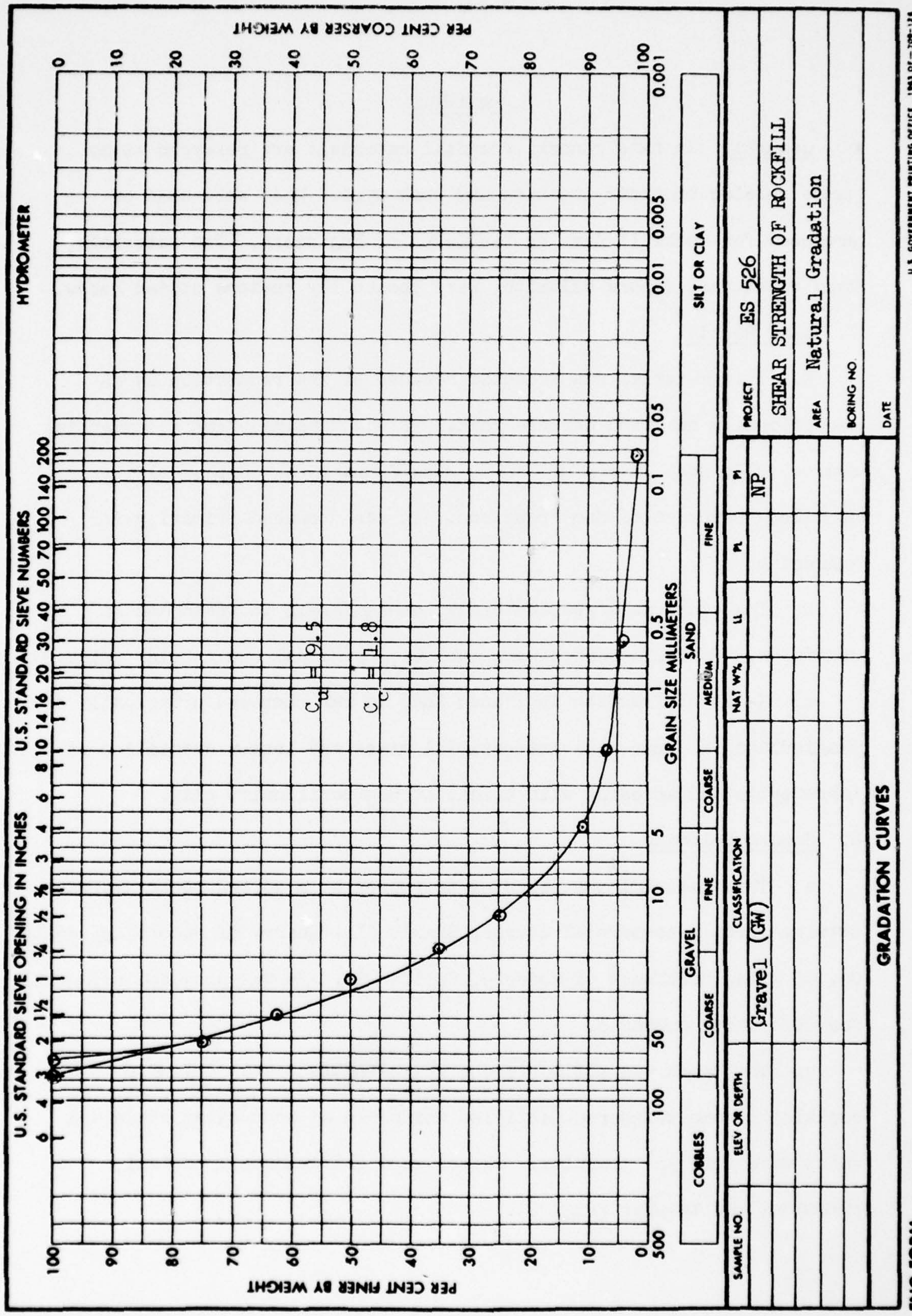
of rockfill dams, consolidation characteristics were also investigated. Seven varieties of crushed rock of varying hardness and mineralogy from the west coast and southeast were tested, as follows:

Napa basalt	Sonora dolomite
New Hogan Dam metavolcanic	Laurel Dam sandstone
Carters Dam quartzite	Buchanan Dam granite
Cougar Dam basalt	

In addition, an alluvial gravel from Black Butte Dam was tested for consolidation only. The test gradation was selected by examining in-place gradations of several existing rockfill dams and determining a modeled gradation, which was referred to as the Natural Gradation (Fig. 1). In order to eliminate the variable of gradation, all tests on all varieties of rock were prepared using this gradation. The maximum particle size in the earlier stages was three inches, but was later reduced to $2\frac{1}{2}$ inches for Sonora dolomite to conform with the more favorable specimen diameter to maximum particle-size ratio of five.

4. Twelve-inch diameter triaxial specimens of each rock type were saturated, and tested in a drained condition at confining pressures of 60, 125, 300 and 400 psi at both maximum and a lower density. Twelve-inch diameter consolidation specimens were tested in both the saturated and dry conditions under axial pressures of 15, 30, 60, 120, 250, 600 and 800 psi only at maximum density. The gradations of all specimens were determined after testing to evaluate particle breakage.

5. Physical properties of each material were determined by the following tests: compressive strength, abrasion loss, specific gravity, soundness by magnesium sulphate, shape factor, scratch hardness, and absorption. Petrographic classifications were performed to determine minerological characteristics.



U.S. STANDARD SIEVE OPENING IN INCHES
U.S. STANDARD SIEVE NUMBERS
HYDROMETER
PER CENT FINER BY WEIGHT
PER CENT COARSER BY WEIGHT
GRAIN SIZE MILLIMETERS
COBBLES
GRAVEL
COARSE
FINE
SAND
COARSE
MEDIUM
FINE
SILT OR CLAY
$C_u = 9.5$
$C_c = 1.8$
SAMPLE NO.
ELEV OR DEPTH
CLASSIFICATION
Gravel (GW)
NAT W%
LL
PL
PI
NP
PROJECT
ES 526
SHEAR STRENGTH OF ROCKFILL
AREA
Natural Gradation
BORING NO.
DATE
GRADATION CURVES
ENG FORM 2087
1 MAY 63
REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE.

FIG. 1

MATERIAL

6. General. In this report, rockfill materials are referred to by names related to their location and rock type. Most were used or proposed for rockfill dams by the Corps of Engineers. Two materials, Napa basalt and Sonora dolomite, were chosen for reasons stated below.

7. Napa Basalt

a. This material was selected because of its reputation as an exceptionally hard and durable rock. It was obtained from a commercial source, Blue Rock Quarry of Basalt Rock Company near Napa, California, 50 miles northeast of San Francisco. It was produced primarily for aggregate.

b. The rock was a grayish-black, dense basalt in fresh and hard condition. Particle shapes were cubical, pyramidal and tabular (Fig. 2).

c. X-ray diffraction indicated that it was composed principally of plagioclase feldspar with interstitial glass and lesser quantities of labradorite and andesine with traces of montmorillonite clay.

8. Sonora Dolomite

a. This material was selected to represent a softer rock. It was obtained from a commercial source, Shaw's Flat Quarry of Sonora Aggregate Co. 65 miles northwest of Modesto, California. It was produced primarily for decorative purposes.

b. This rock was mostly fresh, white to light-gray dolomite containing some weathered particles which had an iron oxide stain and which were soft and granular. Shapes were predominately cubical, pyramidal and tabular (Fig. 2).

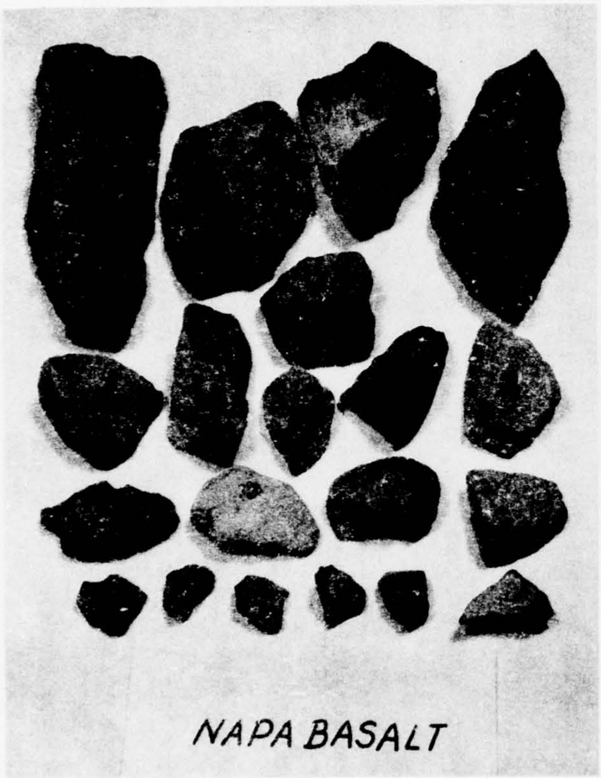


Fig. 2

c. Its origin was the result of dolomitization of a recrystallized limestone. It contained minor quantities of calcite, muscovite, and pyrite.

9. New Hogan Dam Metavolcanic

a. This material was obtained from a quarry one mile downstream from the dam on the Calaveras River, 3 miles from Valley Springs, California, 30 miles east of Stockton. This quarry was developed to produce and process rock specifically for construction of the dam. During construction of the embankment, 1961-1963, this material was used for the outer shell and transition zones.

b. This rock, commonly called greenstone, was light to dark grayish-green, varying from coarse to fine-grained texture, and was in fresh and hard condition. Particle shapes were predominately blocky, elongated, pyramidal and tabular (Fig. 3).

c. It was composed of altered volcanic fragments and ash particles consolidated by epidotization. X-ray diffraction indicates that the constituents were: quartz, epidote, calcite, dolomite, pyrite, and albite feldspar.

10. Carters Dam Quartzite

a. This material was used in the construction of the dam situated on the Cossawattec River 80 miles northwest of Atlanta, Georgia.

b. The rock was a fresh, bluish-gray, medium-grained, hard, impure quartzite composed primarily of interlocking, irregular quartz grains. Particle shapes were predominately cubical, pyramidal, and tabular with a tendency toward flatness in the smaller sizes (Fig. 3).

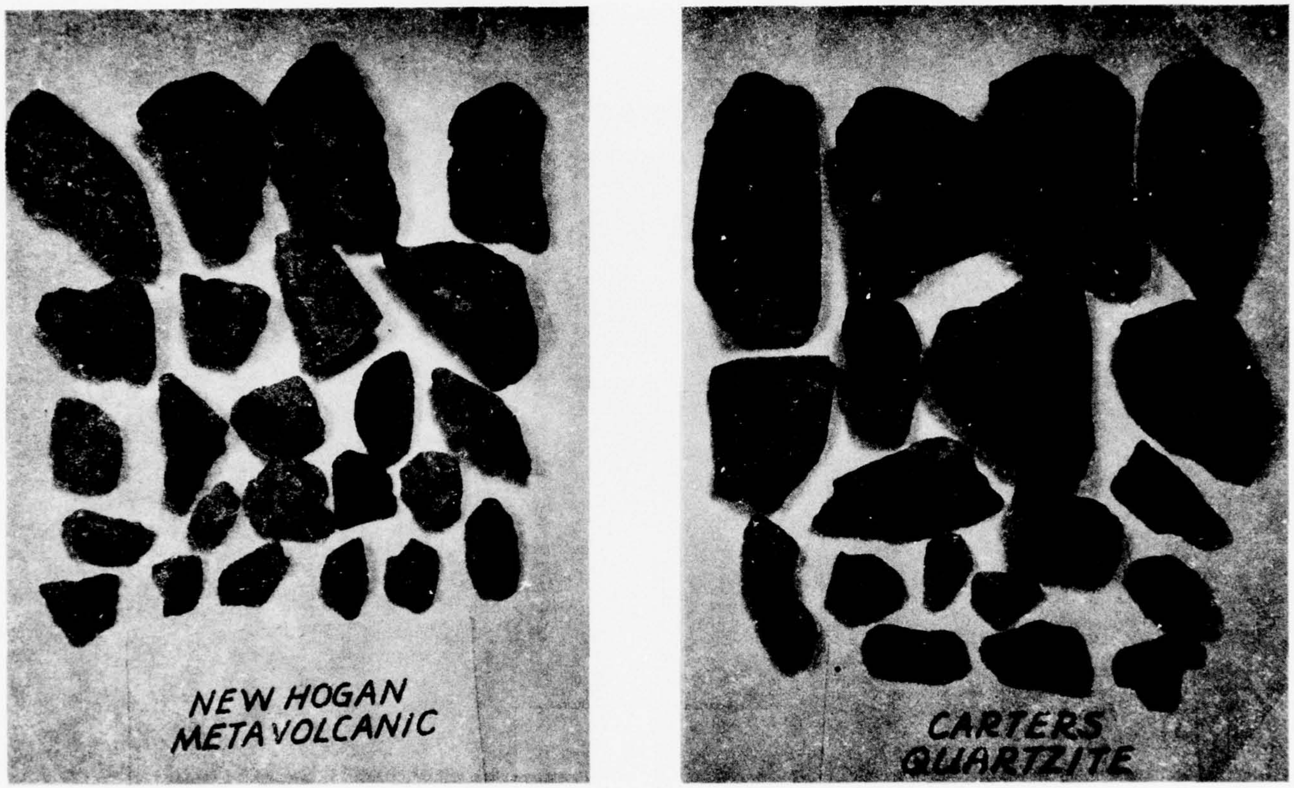


Fig. 3

c. The predominant mineral was quartz, however, x-ray diffraction indicated muscovite, biotite, calcite, and pyrite were also present.

11. Cougar Dam Basalt

a. The dam is 50 miles east of Eugene, Oregon, on the South fork of the McKenzie River. This material was used in the shell of the dam and was obtained from both the spillway excavation and a quarry downstream near the right abutment.

b. The rock was fresh and hard, dark grayish-green to black columnar basalt. Particle shapes were cubical, pyramidal, and wedge-like (Fig. 4). Small vesicles were present in most particles.

c. The rock was composed of plagioclase feldspar with scattered grains of quartz and interstitial glass. X-ray diffraction detected a trace of montmorillonite clay.

12. Laurel Dam Sandstone

a. This dam is on the Laurel River near London, Kentucky, about 90 miles south of Lexington. This material was taken from a bluff upstream from the dam.

b. The rock was porous, argillaceous sandstone from the Pennsylvania formation. The color varied from ochre through light tan to light gray, and the particle shapes were predominately pyramidal and cubical with lesser quantities of wedge and tabular pieces. Edges and corners were well-rounded as a result of abrasion during sieving (Fig. 4).

c. The rock was composed principally of angular to subangular grains of clear quartz and minute quantities of feldspar and muscovite, weakly cemented to varying degrees by a mixture of secondary silica and kaolinite.

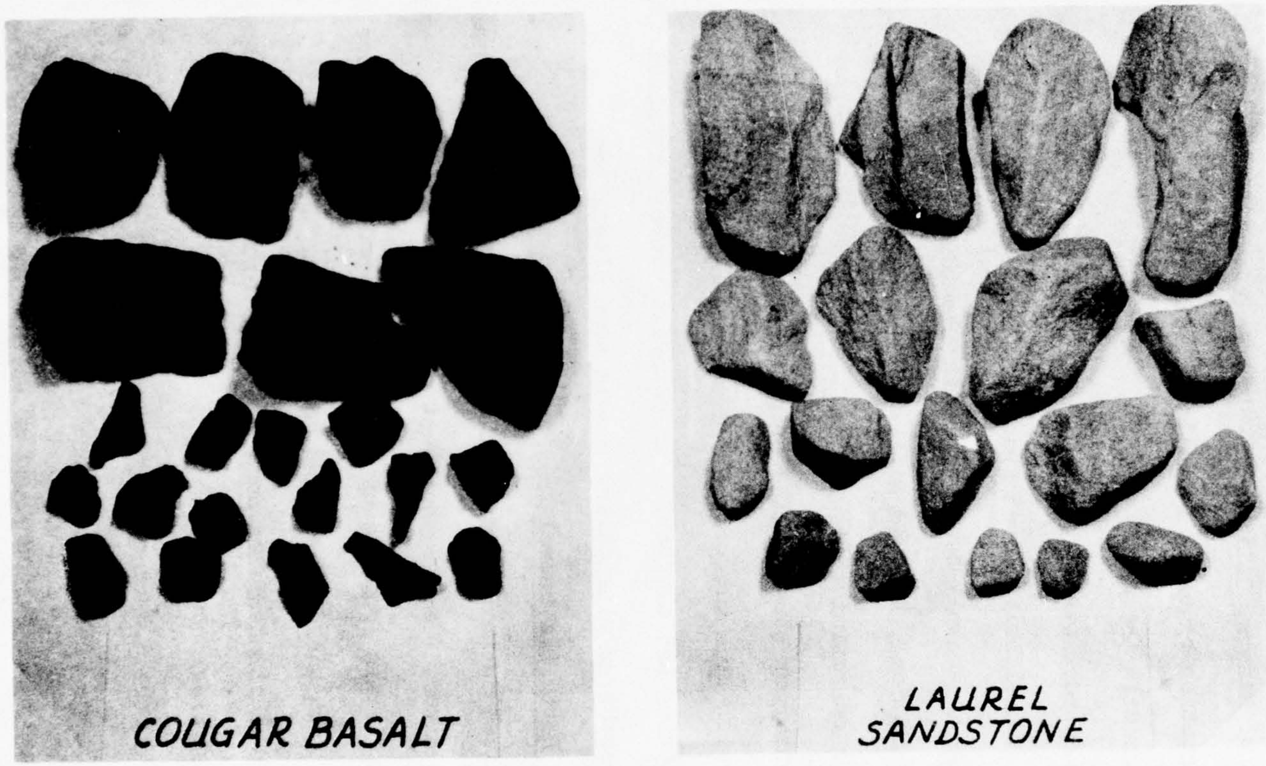


Fig. 4

13. Buchanan Dam Weathered Granite

a. This material was taken from a quarry about $2\frac{1}{2}$ miles upstream from Buchanan Dam which is on the Chowchilla River about 30 miles northeast of Madera, California. The rock was obtained from the surface of the formation by using a shallow blast. It was more weathered than the rock used in the dam.

b. The rock was light gray, medium-grained granodiorite, having many open and tightly-closed fractures. Some particles were soft and friable due to loosely-bonded grains. Particle shapes were mainly cubical, pyramidal, and wedge-like. Edges and corners were rounded in the sieving operation (Fig. 5).

c. The rock was composed of quartz grains, plagioclase feldspar crystals, with some microcline and orthoclase. Biotite flakes, with some weathering and alteration to chlorite, were intermixed throughout. The more weathered plagioclase showed some alteration.

14. Black Butte Dam Gravel

a. Black Butte Dam is located on Stony Creek, a tributary of the Sacramento River, 9 miles northwest of Orland, California. This material was taken from the upper three feet of the streambed one mile downstream from the dam. During construction, this material was used in the pervious section of the dam. In this report, the gravel was tested for consolidation only.

b. The stream channel particles were hard and stream rounded to a subangular shape with distinct but fairly rounded edges (Fig. 5).

c. The gravel was composed of volcanics, quartzite, jasper, vein quartz, and granitic rocks.

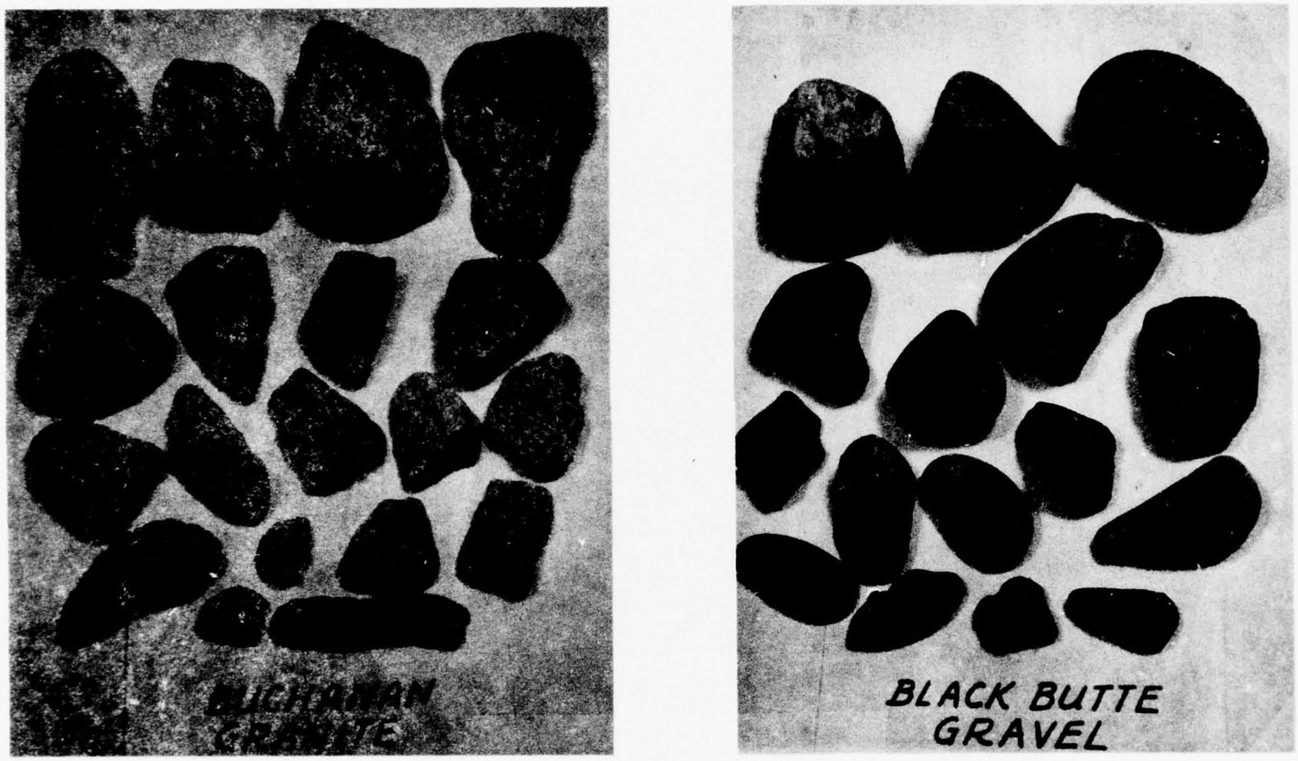


Fig. 5

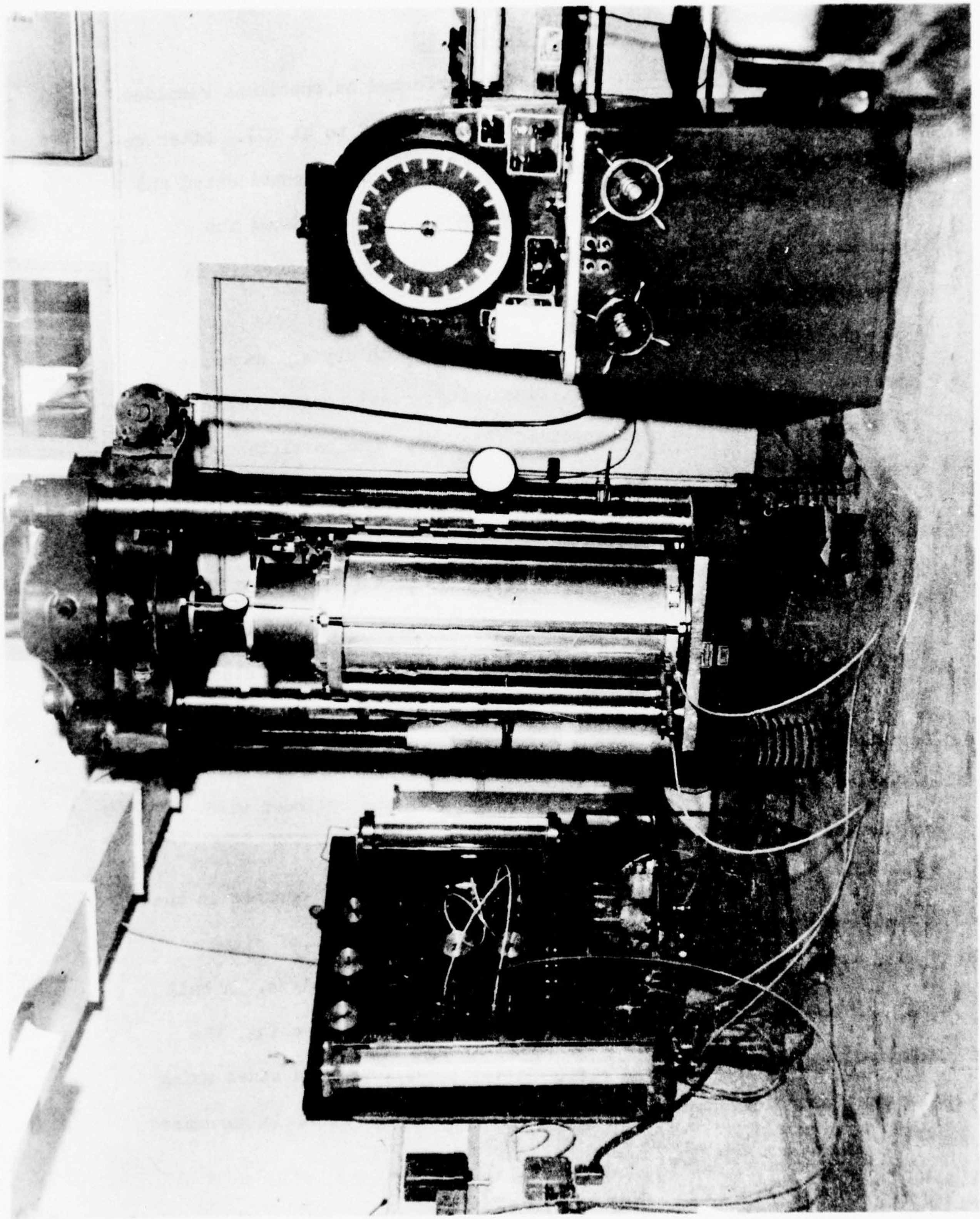
TESTING PROCEDURES

15. Triaxial Compression. Tests were performed on specimens remolded to high density (95 to 100 RD) and low density (9 to 41 RD). After remolding, the specimens were saturated, isotropically consolidated and then loaded axially in a drained condition. Figure 6 shows the apparatus. A detailed description of the testing procedure is in Appendix B.

16. Consolidation. Tests were performed on both dry and saturated specimens in a 12-inch diameter, fixed-ring, steel consolidometer that accommodated a 10-inch high specimen (Fig. 7). The particles were placed into the ring in two layers and vibrated to maximum density. Axial loads were applied by a hydraulic fluid system. Each load remained on the specimens for at least 24 hours. After the final load, the specimen was unloaded incrementally.

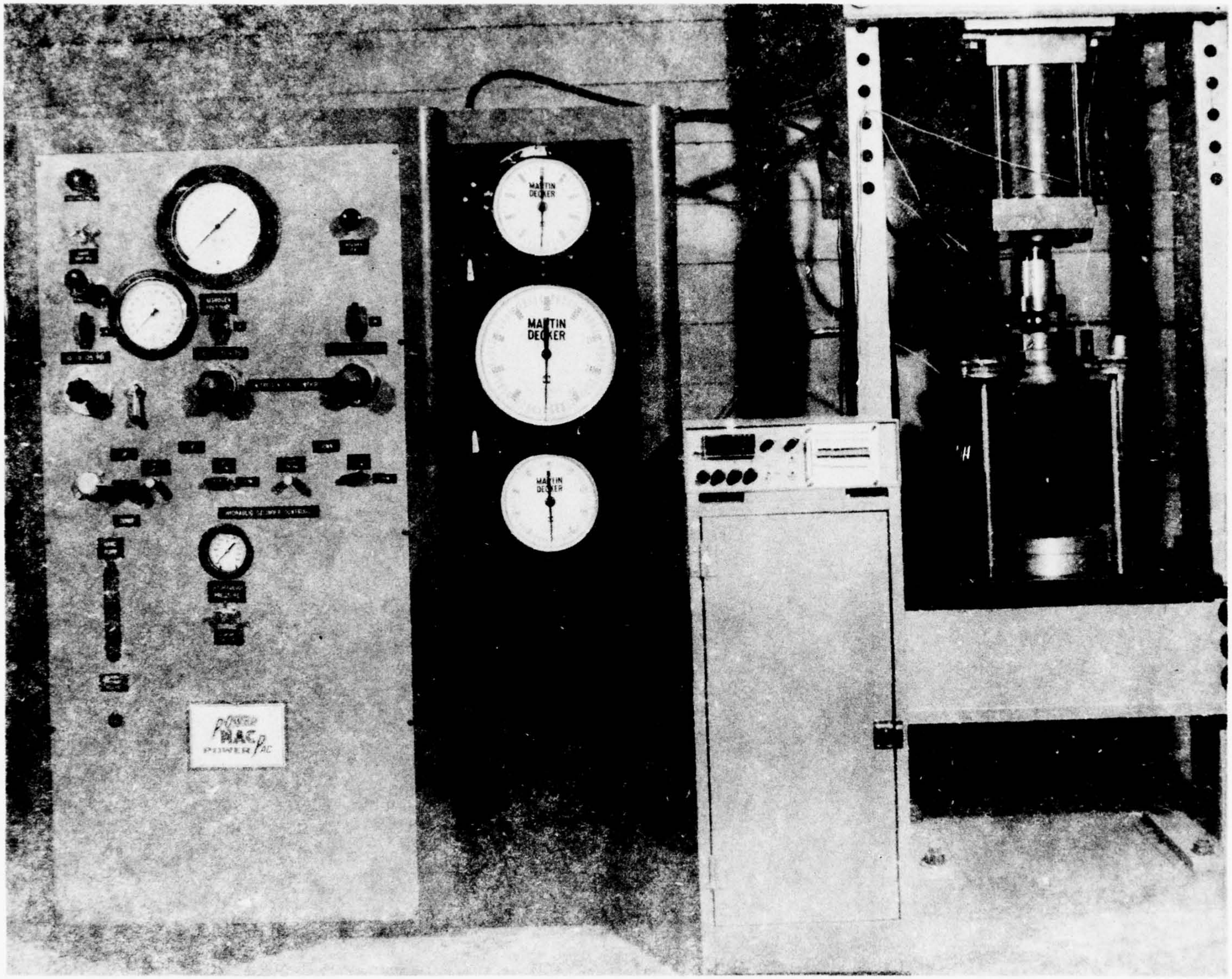
17. Relative Density. Maximum and minimum densities were determined in a 12-inch diameter by 10-inch high cylinder. Vibration for maximum density was provided by a Syntron VP-240 vibratory table. Minimum density was achieved by placing the material in the cylinder without compactive effort.

18. Processing. The rock materials from the dams were crushed in the laboratory using an 8x10-inch jaw crusher for production of sizes larger than 1 inch, and a gyratory crusher for smaller sizes. A ball mill was used to produce sand sizes and fines. After crushing, the material was separated into six gravel sizes and four sand sizes using a trommel and sieve shaker, then washed and dried. Materials purchased



12'' DIAMETER TRIAXIAL SHEAR APPARATUS

FIG. 6



12-INCH DIAMETER CONSOLIDOMETER

Fig. 7

from commercial sources were delivered in from six to eight sizes and were washed and sieved.

19. Tests for Physical Properties.

a. Sieve Analysis and Specific Gravity. Testing method conformed to the procedures described in Engineer Manual, EM-1110-2-1906, "Laboratory Soil Testing," 30 November 1970.

b. Abrasion Loss by Los Angeles Machine and Soundness of Aggregates by Use of Magnesium Sulphate. Test procedures conformed to methods CRD-C 117 and CRD-C 115, respectively, of the Waterways Experiment Station, Concrete Research Division, Corps of Engineers.

c. Compressive Strength. Two-inch diameter cores were drilled from large boulders of each rock type except Laurel sandstone, none being available. The ends of the specimens were ground parallel and perpendicular to the axis of the core. The specimens were soaked overnight then loaded to failure at a rate of 2,000 to 3,000 psi per minute.

d. Scratch Hardness, Moh's Scale. Relative hardness was determined by scratching it with substances of known hardness.

e. Shape Factor (1) is the ratio of the volume of a sphere having a diameter equal to a sieve size to the volume of an average particle passing that sieve. Values were determined from the weighted average of six sieve fractions from 3 inches down to No. 4. A description of the procedure is in Appendix B.

---

(1) Raul J. Marsal, "Strength and Deformation Characteristics of Rockfill," Instituto de Ingenieria, Universidad Nacional Antonoma de Mexico.

20. Particle Breakage. After each triaxial test, the material was sieved for comparison with the initial gradation. Establishment of a parameter to evaluate particle breakage has not yet been established. For this report, the increase in percent passing the D_{10} size of the initial gradation was designated as the parameter for particle breakage.

TEST RESULTS

21. Summary. The purpose of this study was to correlate properties of rockfill materials with shear and consolidation characteristics. There was good correlation of shear strength with abrasion loss, hardness, and compressive strength. Strength was proportional to compressive strength and hardness and inversely proportional to abrasion loss. There was good correlation of shape factor and compressive strength with volumetric and axial strain. Materials with high shape factor and compressive strength exhibited lower strain at failure. For consolidation, strain increased with increasing void ratio and decreasing compressive strength and shape factor. For all materials, greater strain occurred in the saturated than in the dry condition. Dry density was proportional to shape factor and specific gravity.

22. Physical Properties.

a. Abrasion Loss. New Hogan Metavolcanic and Napa basalt values of 13 and 15 percent loss were the lowest of the eight materials (Table 1). Carters quartzite and Cougar basalt values of 26 and 21 also indicated hard fresh materials. Sonora dolomite loss of 42 percent was typical for this type of rock and did not indicate weathering. Laurel sandstone 86 percent loss was due to weak cementation. Buchanan granite value of 69 percent was normal for this type of weathered rock.

TABLE 1

PHYSICAL PROPERTIES

Rock	Abrasion Loss, % Grading		Soundness by $Mg\,SO_4$. Loss, %			Compressive Strength psi	Scratch Hardness Moh's Scale	Shape Factor r_v
	A	B	Coarse	Fine	Average			
Napa Basalt	15	13	2	11	3	30,000	6	0.73
New Hogan Dam Metavolcanic	13	12	1	10	2	20,000	$5\frac{1}{2}$ - 6	0.62
Carters Dam Quartzite	26	25	1	10	2	30,000	$5\frac{1}{2}$ - 6	0.65
Cougar Dam Basalt	21	21	6	42	10	17,000	6	0.54
Sonora Dolomite	42	47	2	43	7	24,000	5	0.66
Buchanan Dam Granite	69	93	25	40	27	*10,000	4	0.64
Laurel Dam Sandstone	86	99	95	54	91	-	$4\frac{1}{2}$	0.59
Black Butte Gravel	22	21	5	23	7	-	-	0.70

For the harder rocks, the results for the A (1½-inch maximum size) and B (3/4-inch maximum size) gradations of each material were similar. Greater loss for Laurel sandstone and Buchanan granite for the B gradation indicated that particles smaller than 3/4 inch were primarily the product of crushing the softest particles of each type. During crushing, the softest rocks broke into the smallest particles.

b. Compressive Strength. The highest strength values (Table 1) were for Napa basalt and Carters quartzite. The New Hogan metavolcanic value was the average of three textural types of this material. Strengths varied from 33,000 psi for the coarse-grained to 13,000 psi for the fine-grained. Cougar basalt value was low probably because of the fine vesicules throughout the sample. The Buchanan granite core was less weathered than the average material used for all other tests.

c. Hardness. The hardness of all fresh materials was consistent with values shown in mineral tables (2) for the predominant minerals in the rocks tested. The low values for Buchanan granite and Laurel sandstone were indications of the degree of weathering and cementation. The values of 4, 5, and 6 (Table 1) are equivalent to the hardness of fluorite, apatite and feldspar on Moh's scale.

d. Soundness by Magnesium Sulphate. For the soundest materials, Napa basalt, New Hogan metavolcanic and Carters quartzite, loss values for both the coarse and fine aggregates were low. Cougar basalt and Sonora dolomite coarse aggregate values were low, but since the fine

---

(2) Arthur S. Eakle, Mineral Tables, 2nd Edition, New York, John Wiley, 1923.

aggregate losses were higher, this indicated that finer sizes may be somewhat weathered. Except for Laurel sandstone and Buchanan granite, weighted average values for each material were similar. Because of this similarity the test was not considered to be particularly valuable for the purpose of this report.

e. Shape Factor. In order to interpret the test values, examples of limiting values are illustrated since this is not a standard test. A sphere that barely passed a particular screen would have a value of 1. Any particle having a volume equal to that sphere would also be 1. A long blocky-shaped particle could have a value greater than 1. A circular, very thin particle that was barely retained on the next smaller screen size would have a value of about 0.002 (assuming that the smaller screen size was one-half of the larger screen size). Results (Table 1) confirmed a visual estimate of the materials except for Black Butte gravel and Cougar basalt. It was anticipated that the gravel would have the highest value because the particles were more rounded than the crushed rocks. Water in the vesicules of Cougar basalt caused a higher than normal saturated surface-dry water content which affected the volume determination and resulted in a low value. Edges and corners of the soft rocks were rounded during the sieving operation which resulted in higher shape factors than would be obtained from unsieved material. Figure 8 shows higher shape factor values for one-inch size and larger. Lower values for smaller sizes are mainly due to the great number of angular fragments resulting from crushing.

f. Specific Gravity and Absorption. Specific gravity results (Table 2) are consistent with the mineral composition of the materials. The highest absorptions and lowest bulk specific gravities were for Laurel sandstone and Cougar basalt.

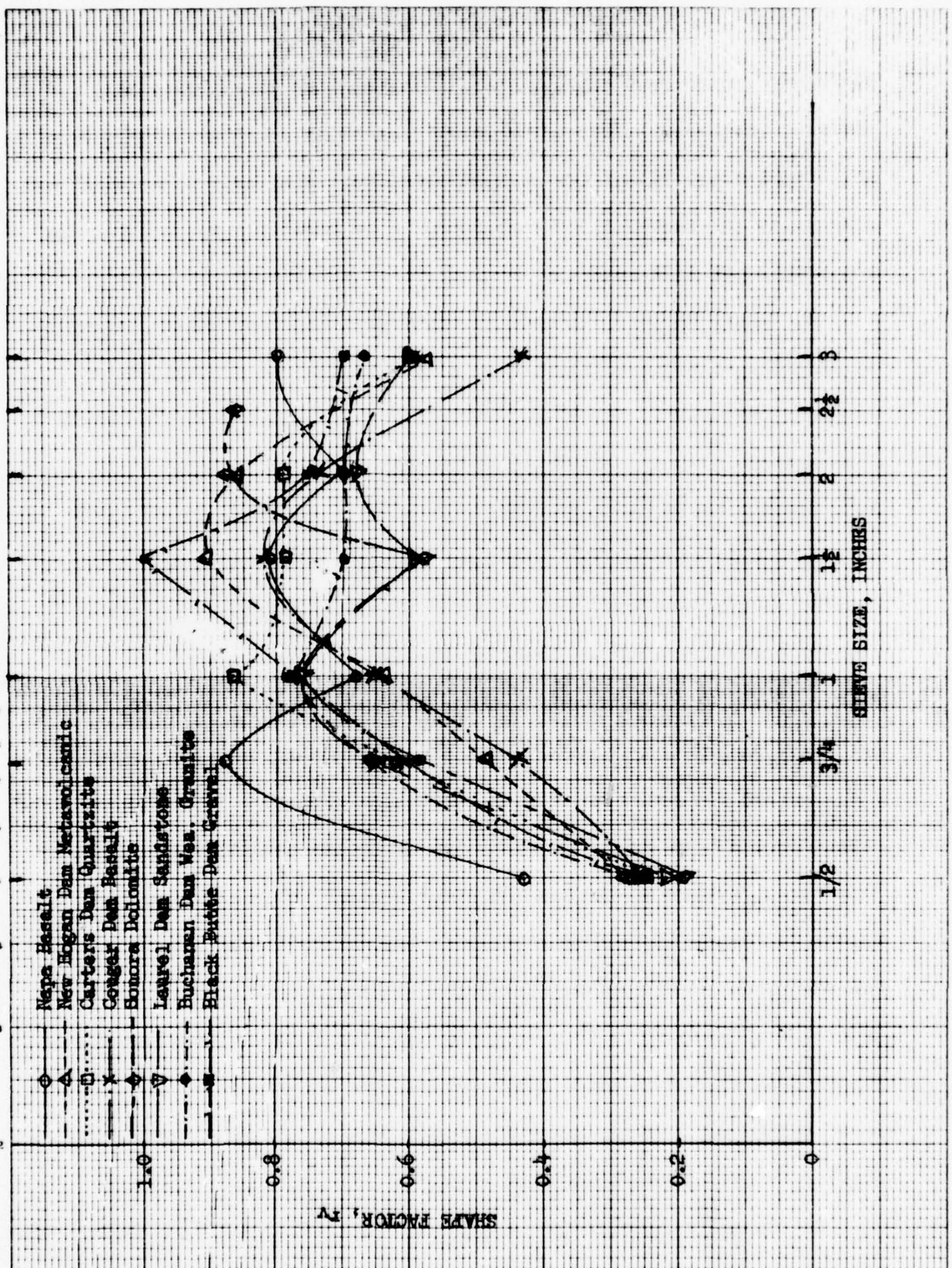

Napa Basalt
New Hogan Dam Metavolcanic
Carters Dam Quartzite
Cougar Dam Basalt
Sonora Dolomite
Laurel Dam Sandstone
Buchanan Dam Wash. Granite
Black Butte Dam Gravel
SHAPE FACTOR, Fv
1.0
0.8
0.6
0.4
0.2
0
SIEVE SIZE, INCHES
1/2
3/4
1
1½
2
2½
3

FIG 8

TABLE 2

SPECIFIC GRAVITY & ABSORPTION

Rock	Specific Gravity +No. 4 Bulk	Specific Gravity +No. 4 Appar.	Specific Gravity -No. 4 Solids	Absorption %
Napa Basalt	2.82	2.87	2.85	0.8
New Hogan Dam Metabolcanic	2.84	2.85	2.82	0.4
Carters Dam Quartzite	2.69	2.73	2.72	0.4
Cougar Dam Basalt	2.60	2.74	2.75	1.9
Sonora Dolomite	2.83	2.86	2.82	0.6
Buchanan Dam Granite	2.62	2.69	2.69	0.9
Laurel Dam Sandstone	2.29	2.65	2.64	3.9
Black Butte Gravel	2.69	2.75	2.70	0.9

23. Classification of Materials. On the basis of physical properties and petrographic analysis, the rockfill materials were classified as follows:

Fresh & Hard	Intermediate	Soft or Weathered
Napa basalt	Sonora dolomite	Laurel sandstone
Carters quartzite		Buchanan granite
New Hogan metavolcanic		
Cougar basalt		

Sonora dolomite was considered an intermediate material since it exhibited characteristics of both groups. Cougar basalt contained many vesicular pieces and some of the results, particularly shape factor, absorption, and soundness, were apparently influenced by the presence of the vesicules. This material was classified as fresh and hard since there was no visual evidence of weathering.

24. Triaxial Compression Tests.

a. General. The angle of internal friction is defined as the angle formed by a line through the origin and tangent to the Mohr circle. Since the strength of granular materials varied with density, test results were normalized by interpolation at 100 percent relative density except when the variable of density was illustrated. Figures which illustrated physical property results were plotted for the lowest and highest confining pressures, 60 and 400 psi. Since triaxial test results were normalized, the only variable was the variety of material. A plot of

axial strain at failure at confining pressures greater than 60 psi were not presented because many low-density specimens did not reach peak strength before the strain limit of the apparatus was reached. Test results are summarized in Appendix A on Plates A1 to A7 and test curves are plotted on Plates A8 to A35.

b. Shear Strength. For all materials, strength decreased with increasing confining pressure (Fig. 9). The rate of decrease was greatest at low pressure. As confining pressure increased, differences in strength between materials diminished. Strength difference was 10 degrees (49.5 to 39.4) at 60 psi confining pressure and at 400 psi the difference was 3 degrees (38.6 to 35.3). At 400 psi, there was 1.5 degree difference between six of the seven materials. Shape and position of the soft rock curves indicated that strength of these materials was less affected by confining pressures than the harder rocks. Sonora dolomite reacted as a hard material at low pressure and as a soft material at high pressure. Strength increased with decreasing abrasion loss and with increasing compressive strength (Fig. 10a & b). Except for the two softest materials, strength was not affected by soundness (Fig. 10c). Strength also increased with hardness (Fig. 11a), and there was a trend of increasing strength with increasing shape factor (Fig. 11b). Strength was proportional to density; however, hard rock increased at a greater rate than the other materials (Fig. 12 & 13).

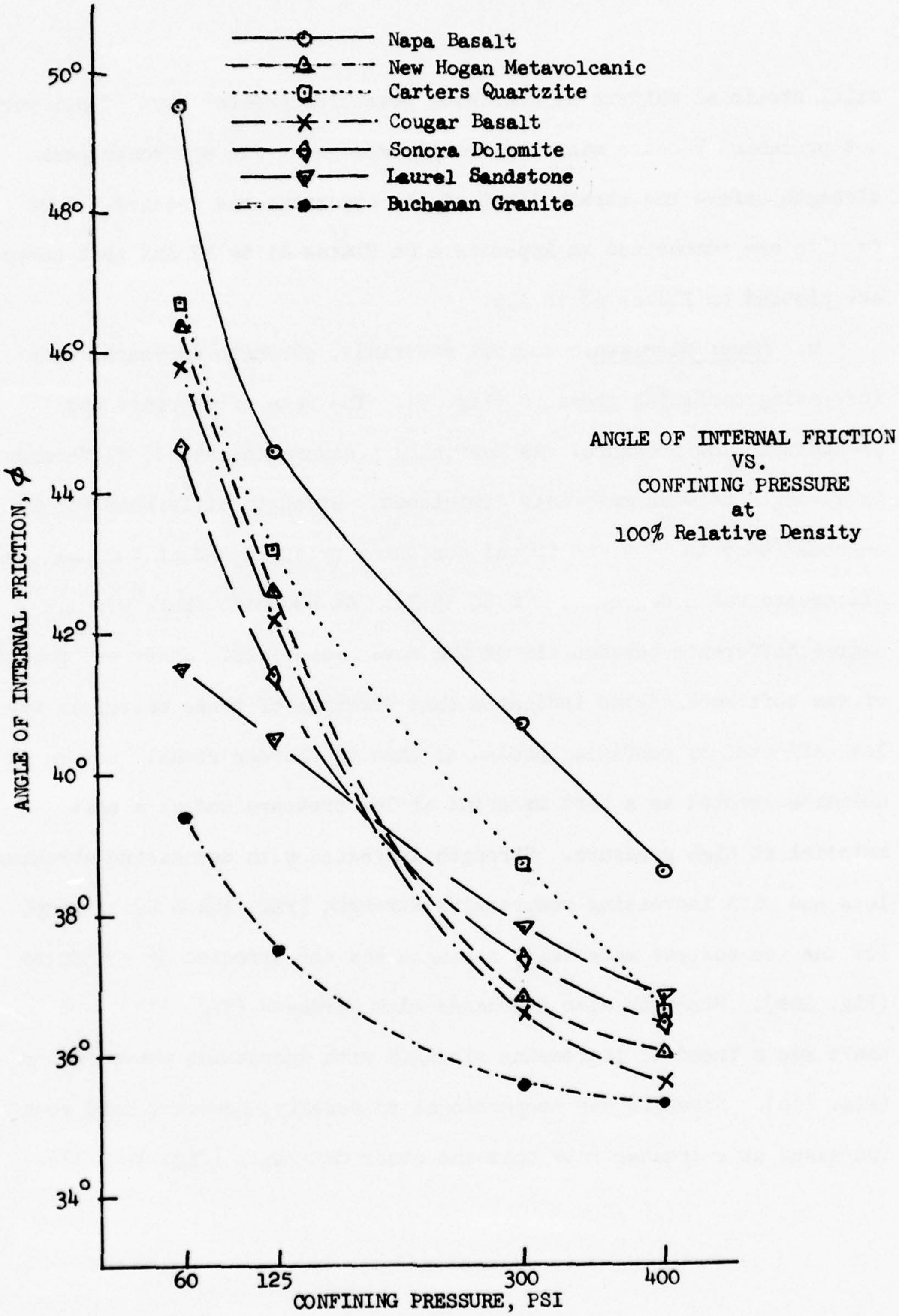

Napa Basalt
New Hogan Metavolcanic
Carters Quartzite
Cougar Basalt
Sonora Dolomite
Laurel Sandstone
Buchanan Granite
ANGLE OF INTERNAL FRICTION
VS.
CONFINING PRESSURE
at
100% Relative Density
ANGLE OF INTERNAL FRICTION, ϕ
50°
48°
46°
44°
42°
40°
38°
36°
34°
60
125
300
400
CONFINING PRESSURE, PSI

FIG 9

ANGLE OF INTERNAL FRICTION
VS.
PHYSICAL PROPERTIES
of
60 and 400 psi Confining Pressure
Specimens at 100% RD

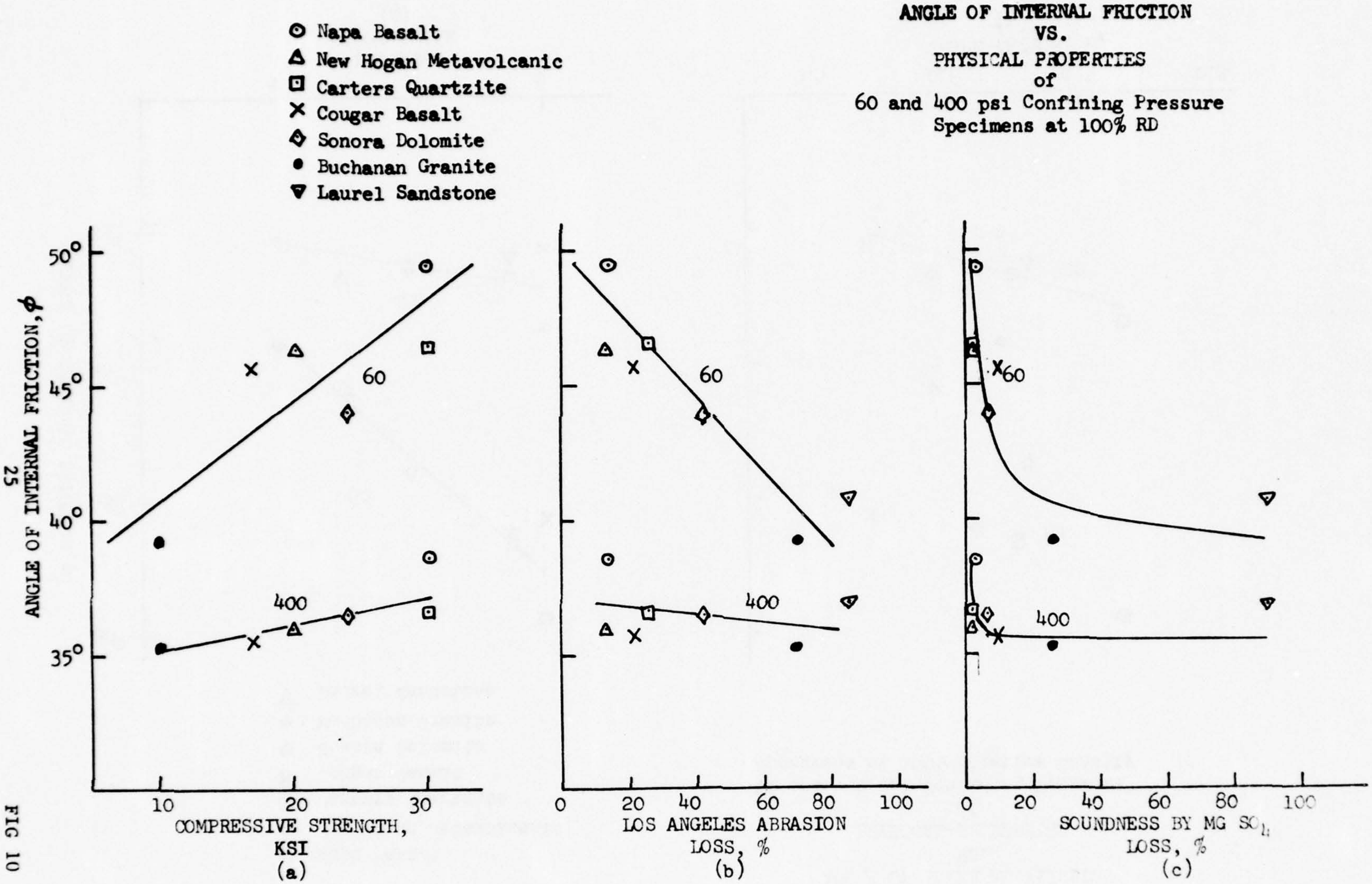


FIG 10

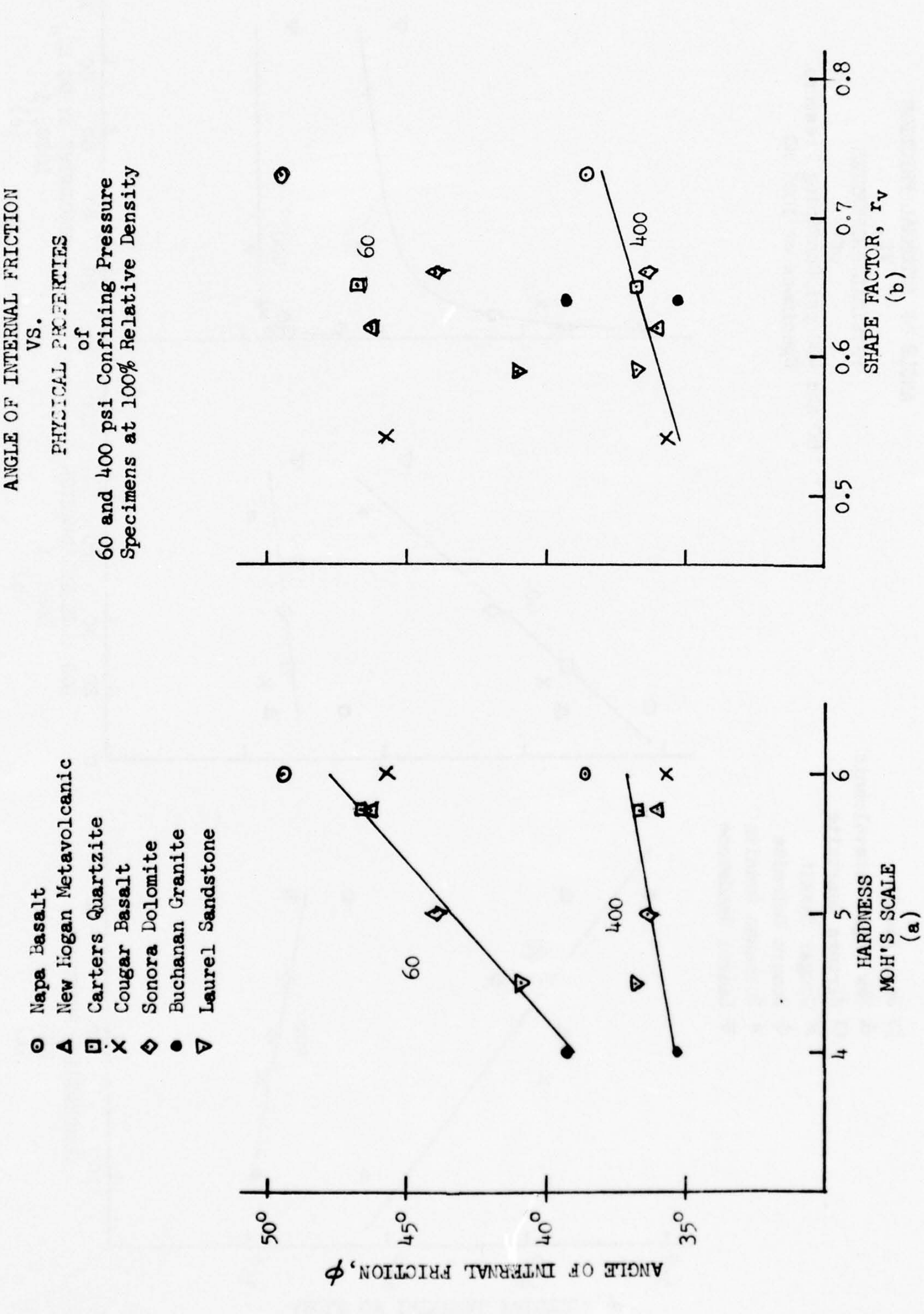
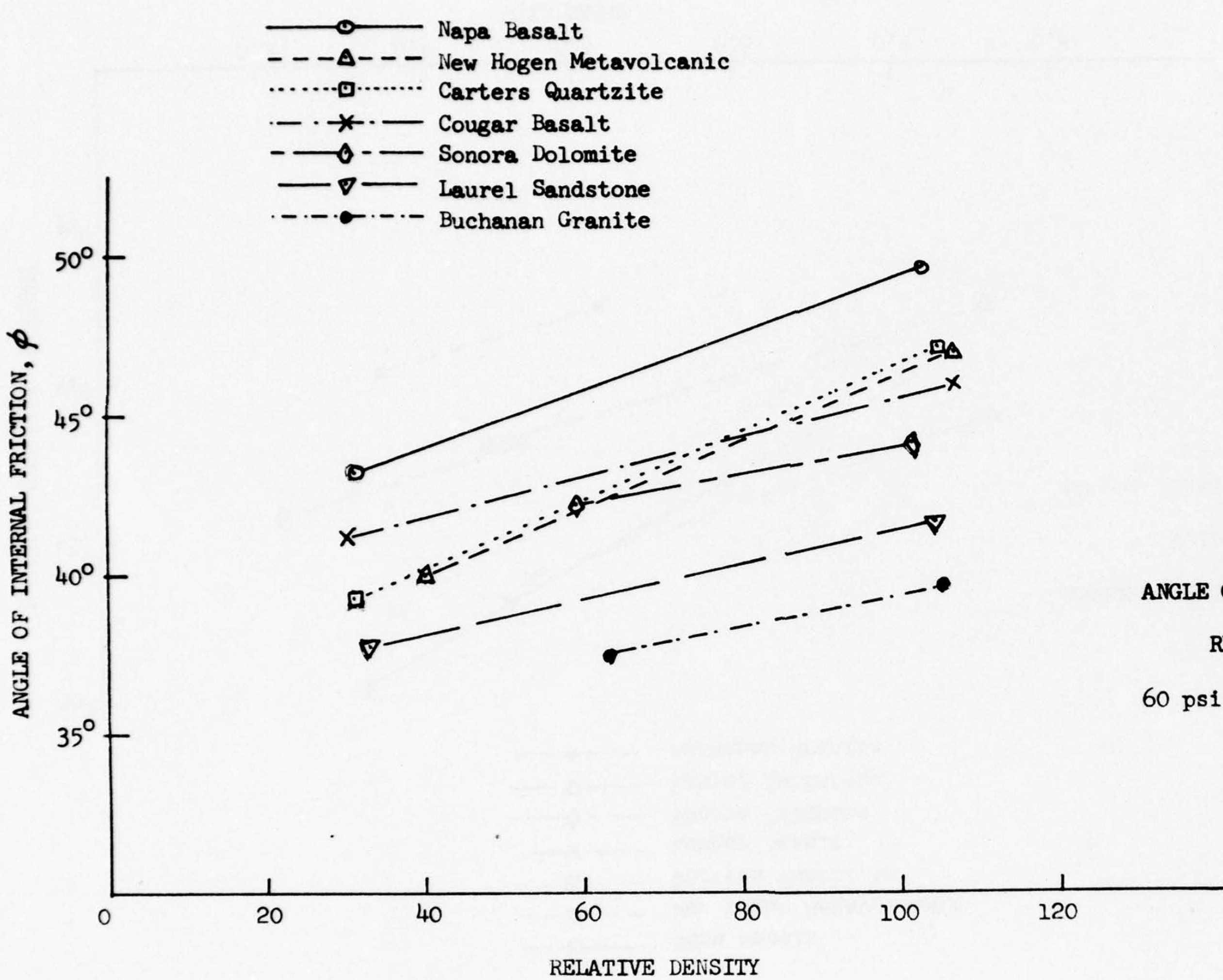
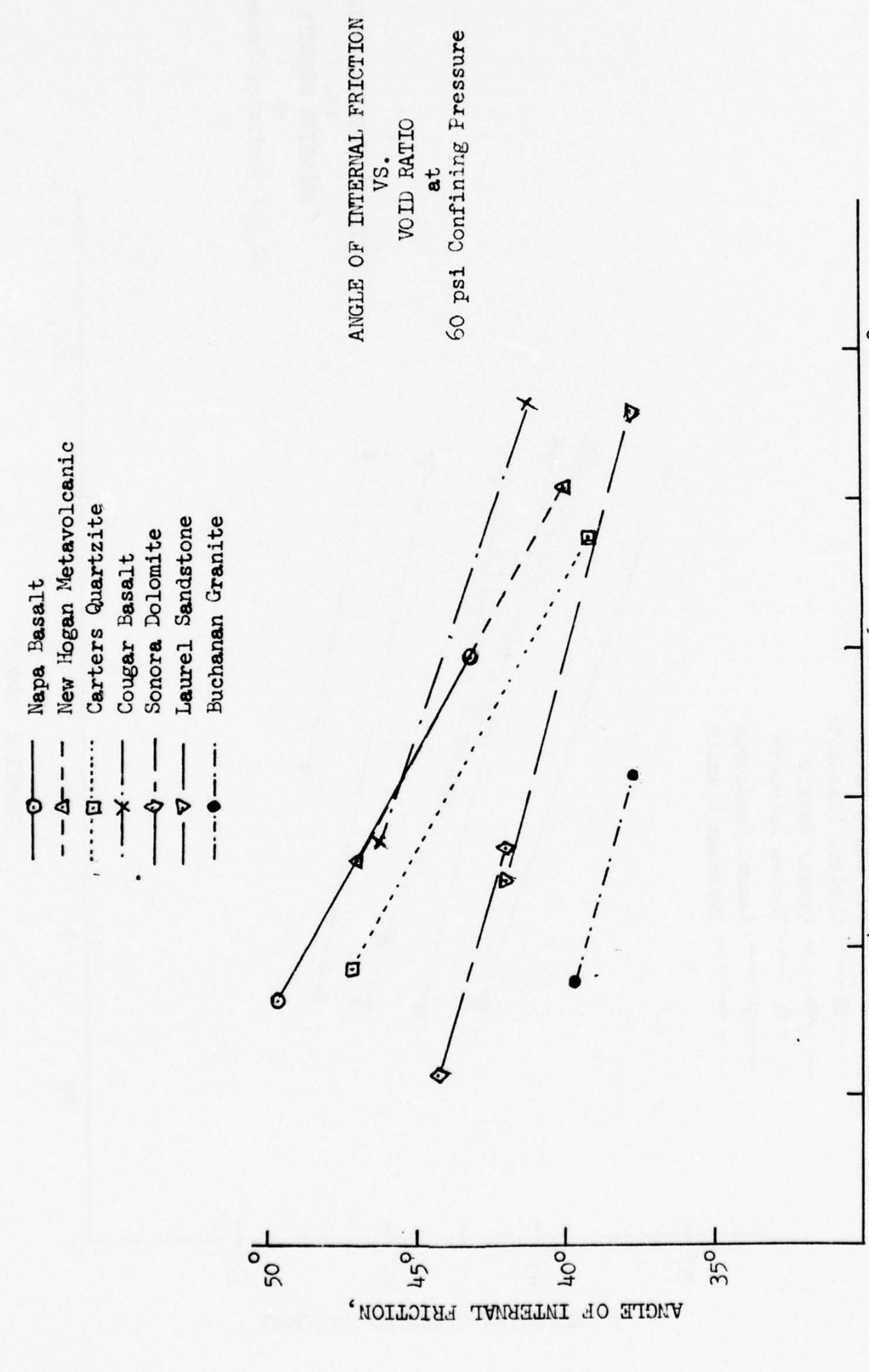

ANGLE OF INTERNAL FRICTION
VS.
PHYSICAL PROPERTIES
of
60 and 400 psi Confining Pressure
Specimens at 100% Relative Density
Napa Basalt
New Hogan Metavolcanic
Carters Quartzite
Cougar Basalt
Sonora Dolomite
Buchanan Granite
Laurel Sandstone
ANGLE OF INTERNAL FRICTION, φ
50°
45°
40°
35°
60
400
4
5
6
HARDNESS
MOH'S SCALE
(a)
0.5
0.6
0.7
0.8
SHAPE FACTOR, r_v
(b)

FIG 11



ANGLE OF INTERNAL FRICTION
VS.
RELATIVE DENSITY
at
60 psi Confining Pressure

FIG 12



ANGLE OF INTERNAL FRICTION
VS.
VOID RATIO
at
60 psi Confining Pressure
Napa Basalt
New Hogan Metavolcanic
Carters Quartzite
Cougar Basalt
Sonora Dolomite
Laurel Sandstone
Buchanan Granite
ANGLE OF INTERNAL FRICTION,
50°
45°
40°
35°
0.3
0.4
0.5
0.6
0.7
0.8
VOID RATIO

FIG 13

c. Isotropic Consolidation. Consolidation was evaluated by the equation:

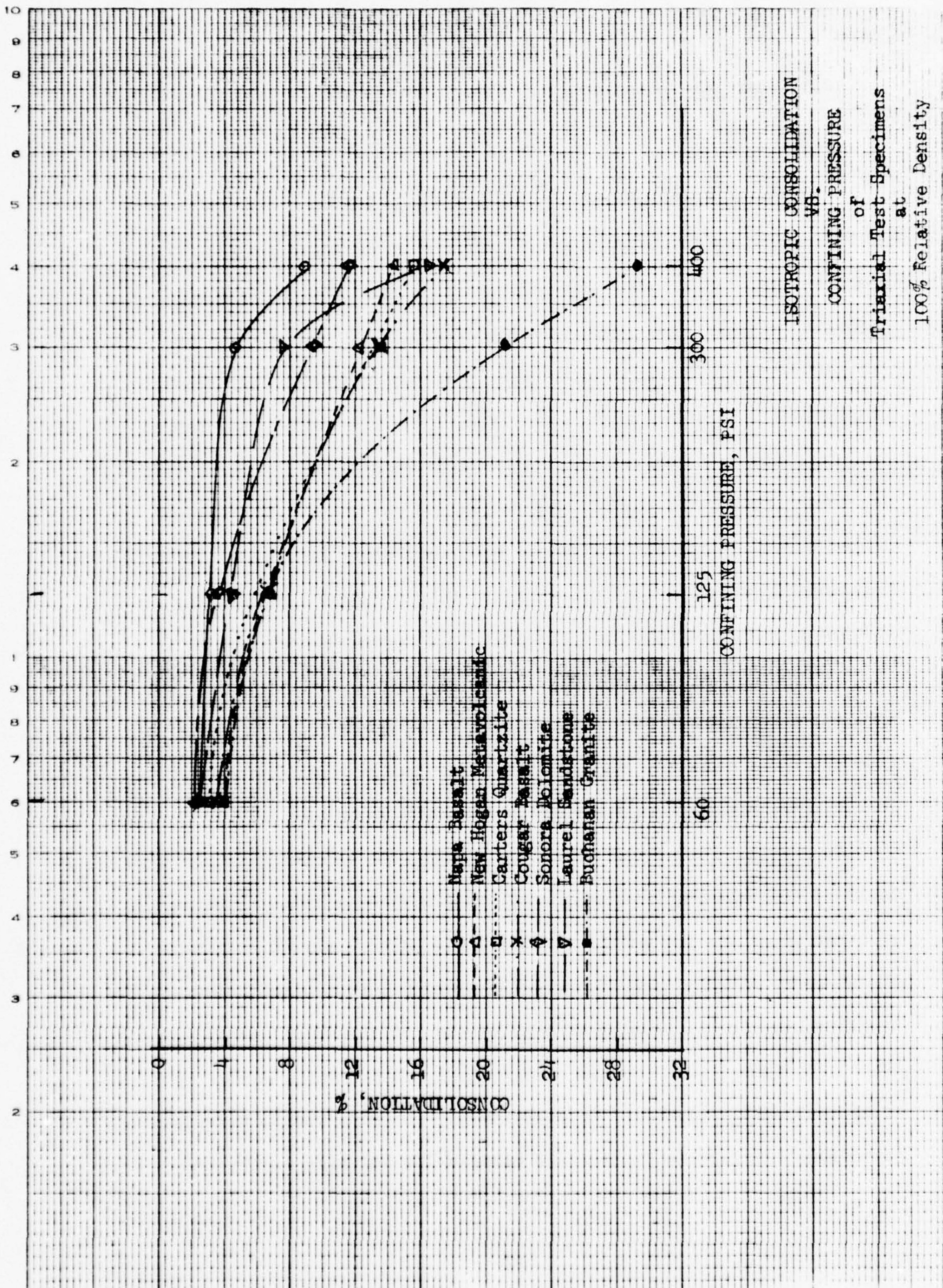
$$\text{Percent Consolidation} = \frac{\text{Volume Change}}{\text{Original Volume}} \times 100$$

At 400 psi, greatest consolidation occurred on Buchanan granite, 29.3 percent (Fig. 14). Least compression was on Napa basalt and Sonora dolomite, 8.8 and 11.6 percent, respectively.

d. Volumetric Strain at Failure. Volume change at failure was proportional to confining pressure (Fig. 15). For soft rocks, Laurel sandstone and Buchanan granite, the rate decreased sharply at 125 psi; for harder rocks, the change occurred at 300 psi except for Napa and Cougar basalts which did not decrease appreciably. Figure 16 shows the relationship with physical properties. Volume change appeared to be related to particle shape and possibly to compressive strength.

e. Axial Strain at Failure. Axial strain at failure was influenced by shape factor and compressive strength (Fig. 17a & c). In general, axial strain at failure increased with confining pressure. Results are tabulated in the summary tables (Appendix A).

f. Particle Breakage. Breakage of only the largest particle size could be evaluated by examination of the gradation curves. Breakage of other sizes was impossible to assess because of carry-over from the screens. At the highest confining pressure, the 2-inch rock size of all materials was reduced from 25 percent of the total sample before testing to from 2 to 12 percent after testing. Gradation curves of all samples after testing are contained in Appendix A. For hard rocks, there was no significant difference in breakage between low and high density specimens;



ISOTROPIC CONSOLIDATION
VS.
CONFINING PRESSURE
of
Triaxial Test Specimens
at
100% Relative Density
CONFINING PRESSURE, PSI
60
125
300
400
CONSOLIDATION, %
0
4
8
12
16
20
24
28
32
Napa Basalt
New Hogan Metavolcanic
Carters Quartzite
Cougar Basalt
Sonora Dolomite
Laurel Sandstone
Buchanan Granite

FIG 14

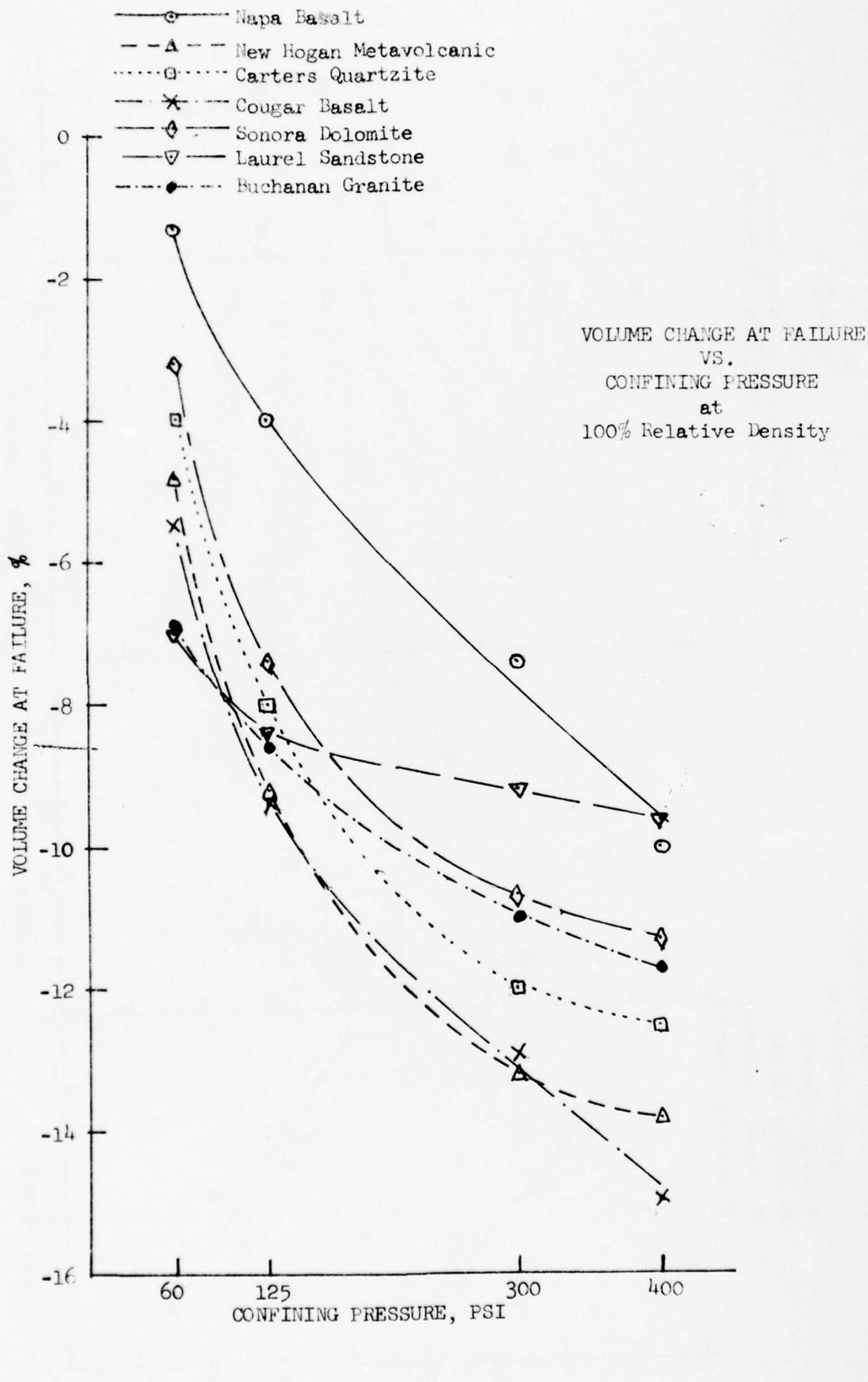
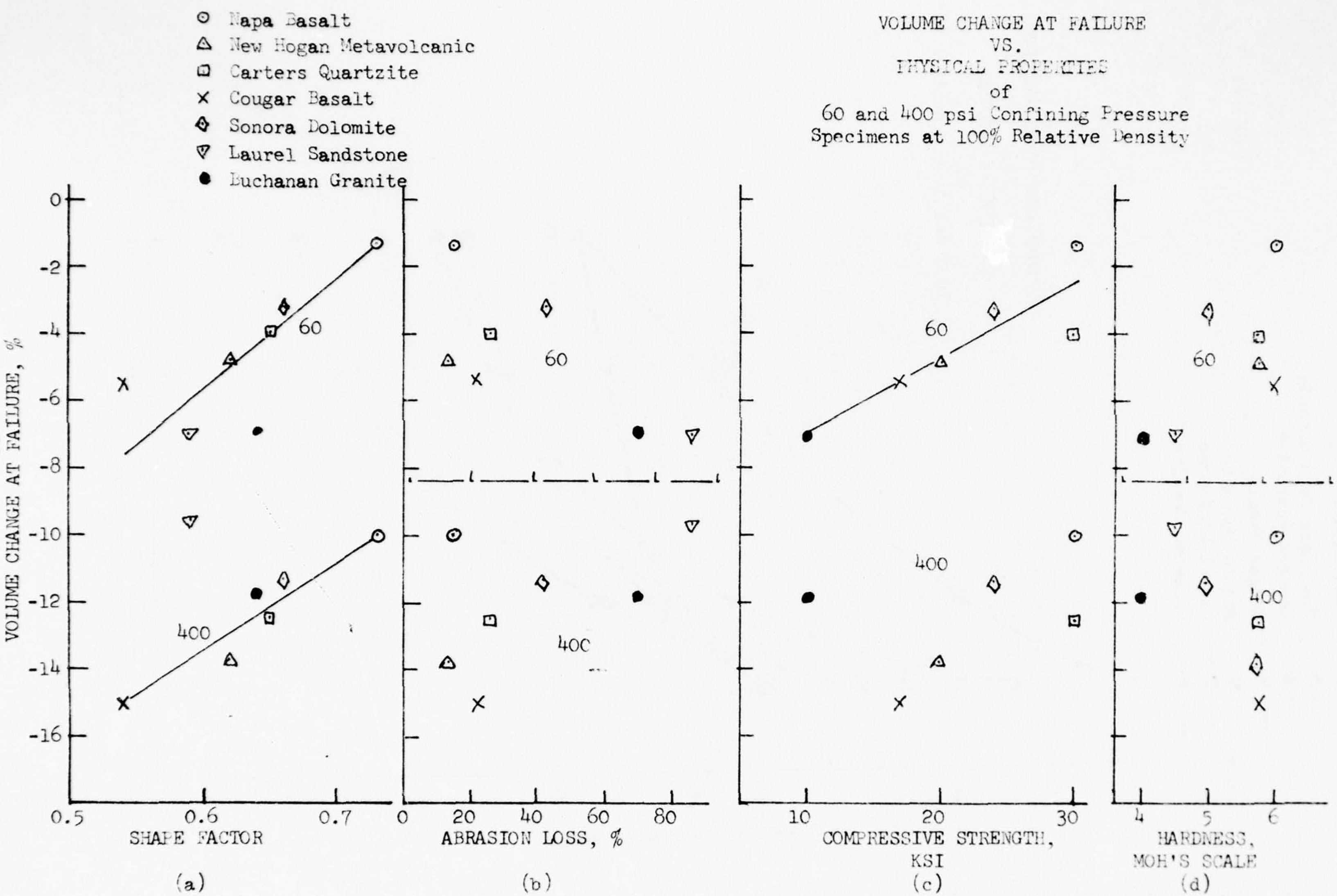

Napa Basalt
New Hogan Metavolcanic
Carters Quartzite
Cougar Basalt
Sonora Dolomite
Laurel Sandstone
Buchanan Granite
VOLUME CHANGE AT FAILURE
VS.
CONFINING PRESSURE
at
100% Relative Density
VOLUME CHANGE AT FAILURE, %
0
-2
-4
-6
-8
-10
-12
-14
-16
60
125
300
400
CONFINING PRESSURE, PSI

FIG 15



VOLUME CHANGE AT FAILURE
VS.
PHYSICAL PROPERTIES
of
60 and 400 psi Confining Pressure
Specimens at 100% Relative Density
Napa Basalt
New Hogan Metavolcanic
Carters Quartzite
Cougar Basalt
Sonora Dolomite
Laurel Sandstone
Buchanan Granite
VOLUME CHANGE AT FAILURE, %
0
-2
-4
-6
-8
-10
-12
-14
-16
60
400
0.5
0.6
0.7
SHAPE FACTOR
(a)
0
20
40
60
80
ABRASION LOSS, %
(b)
10
20
30
COMPRESSIVE STRENGTH,
KSI
(c)
4
5
6
HARDNESS,
MOH'S SCALE
(d)

FIG 16

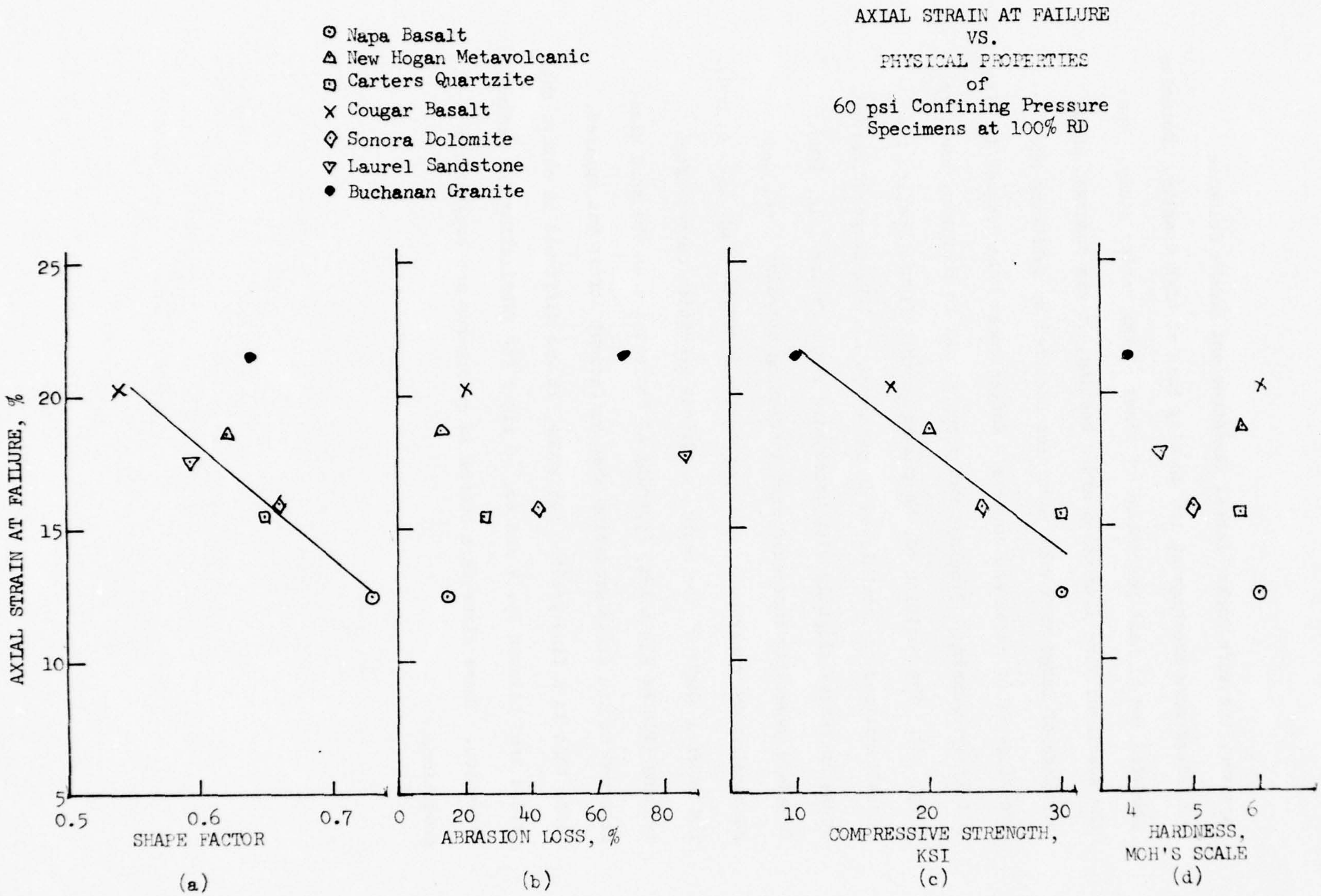
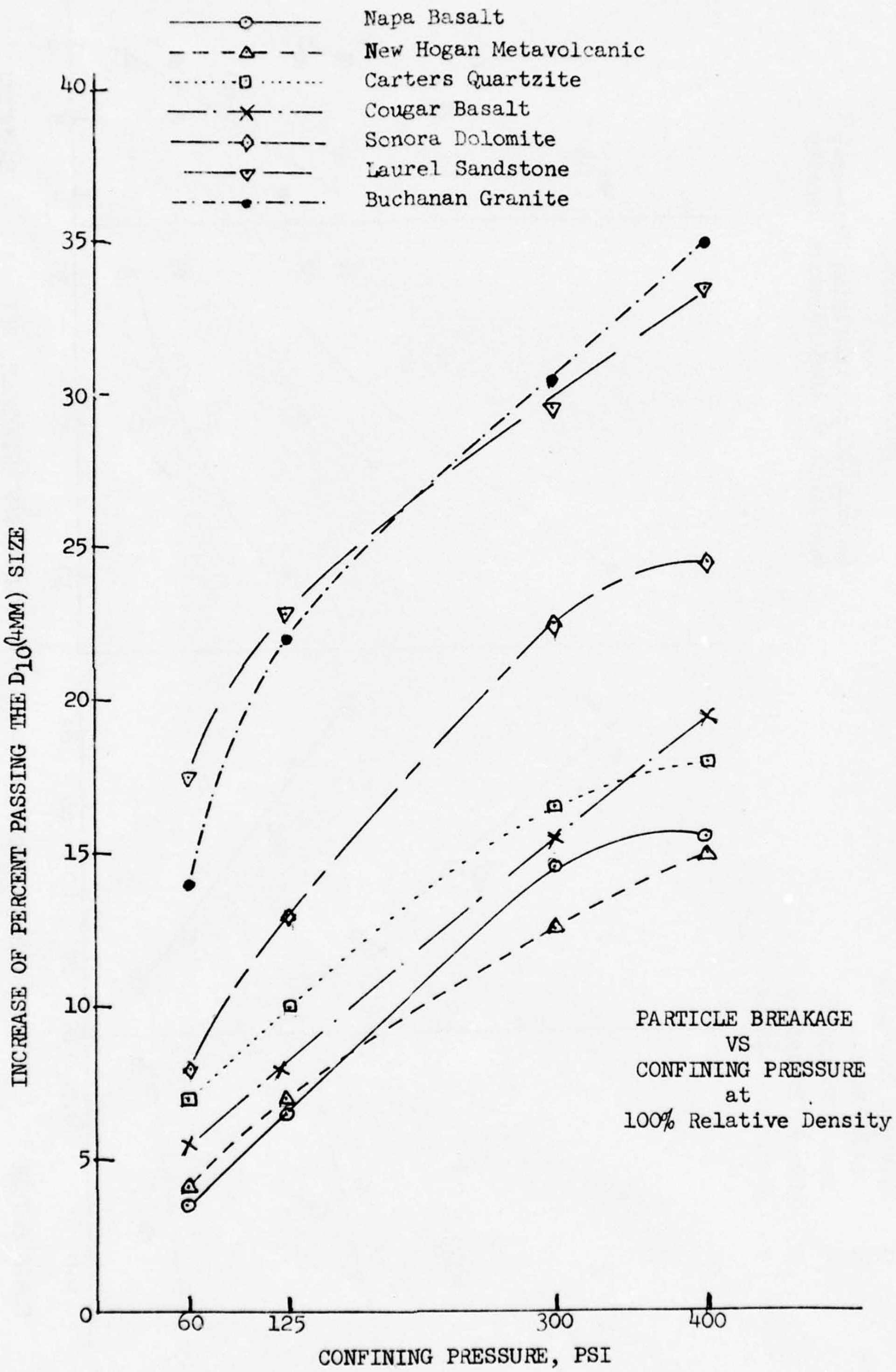

AXIAL STRAIN AT FAILURE
VS.
PHYSICAL PROPERTIES
of
60 psi Confining Pressure
Specimens at 100% RD
Napa Basalt
New Hogan Metavolcanic
Carters Quartzite
Cougar Basalt
Sonora Dolomite
Laurel Sandstone
Buchanan Granite
AXIAL STRAIN AT FAILURE, %
25
20
15
10
5
0.5
0.6
0.7
SHAPE FACTOR
(a)
0
20
40
60
80
ABRASION LOSS, %
(b)
10
20
30
COMPRESSIVE STRENGTH,
KSI
(c)
4
5
6
HARDNESS,
MOH'S SCALE
(d)

FIG 17

however, the soft rocks, Laurel sandstone and Sonora dolomite exhibited more breakage at low density than at high density. Dolomite produced the highest percentage of fines of the entire study. When the specimens were dismantled after testing, it was observed that breakage of large hard rock particles occurred by splitting and breaking-off of edges and corners. Softer rocks were reduced in size mainly by crushing. Breakage was proportional to confining pressure (Fig. 18). The position of the curves on this figure confirm the classifications as established in paragraph 23. Breakage of harder rocks increased slightly with decreasing shape factor (Fig. 19a). Breakage generally increased with increasing abrasion loss, and decreasing Moh's hardness and compressive strength (Fig. 19b, c, & d). The unusual shape of the Laurel sandstone gradation curves after testing (Plates A30 & A31, Appendix A) indicated that the sand sizes returned to its field gradation when sufficient stress was applied. Since this is a fine-grained sandstone, it was difficult to obtain the needed sand between No. 4 and No. 60 sizes for fabricating the desired gradation. These sizes were scarce in quarry-run and crusher-run gradations.



Napa Basalt
New Hogan Metavolcanic
Carters Quartzite
Cougar Basalt
Sonora Dolomite
Laurel Sandstone
Buchanan Granite
40
35
30
25
20
15
10
5
0
INCREASE OF PERCENT PASSING THE D_{10}(4MM) SIZE
60
125
300
400
CONFINING PRESSURE, PSI
PARTICLE BREAKAGE
VS
CONFINING PRESSURE
at
100% Relative Density

FIG 18

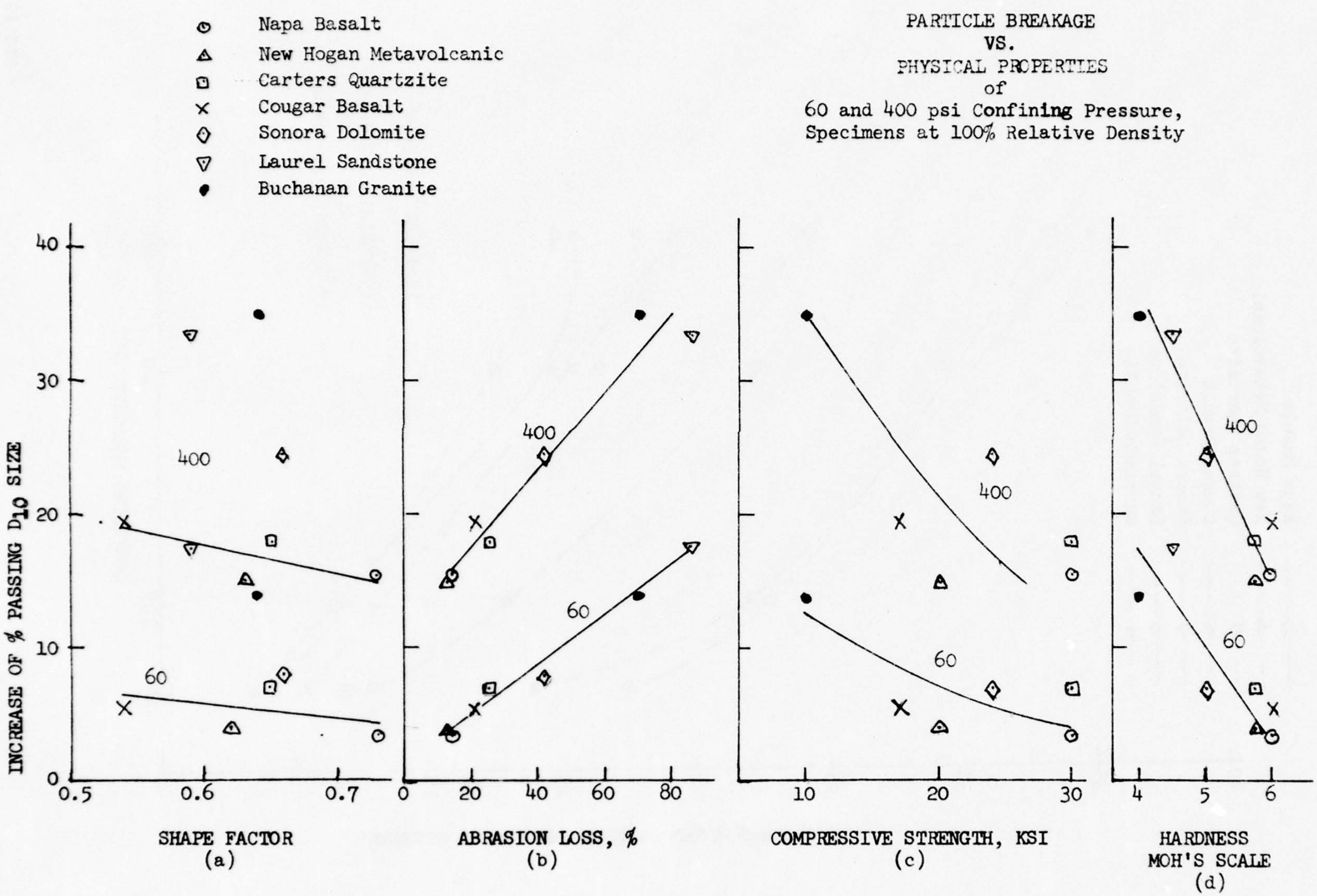

PARTICLE BREAKAGE
VS.
PHYSICAL PROPERTIES
of
60 and 400 psi Confining Pressure,
Specimens at 100% Relative Density
Napa Basalt
New Hogan Metavolcanic
Carters Quartzite
Cougar Basalt
Sonora Dolomite
Laurel Sandstone
Buchanan Granite
INCREASE OF % PASSING D_{10} SIZE
400
60
SHAPE FACTOR
(a)
ABRASION LOSS, %
(b)
COMPRESSIVE STRENGTH, KSI
(c)
HARDNESS
MOH'S SCALE
(d)

FIG 19

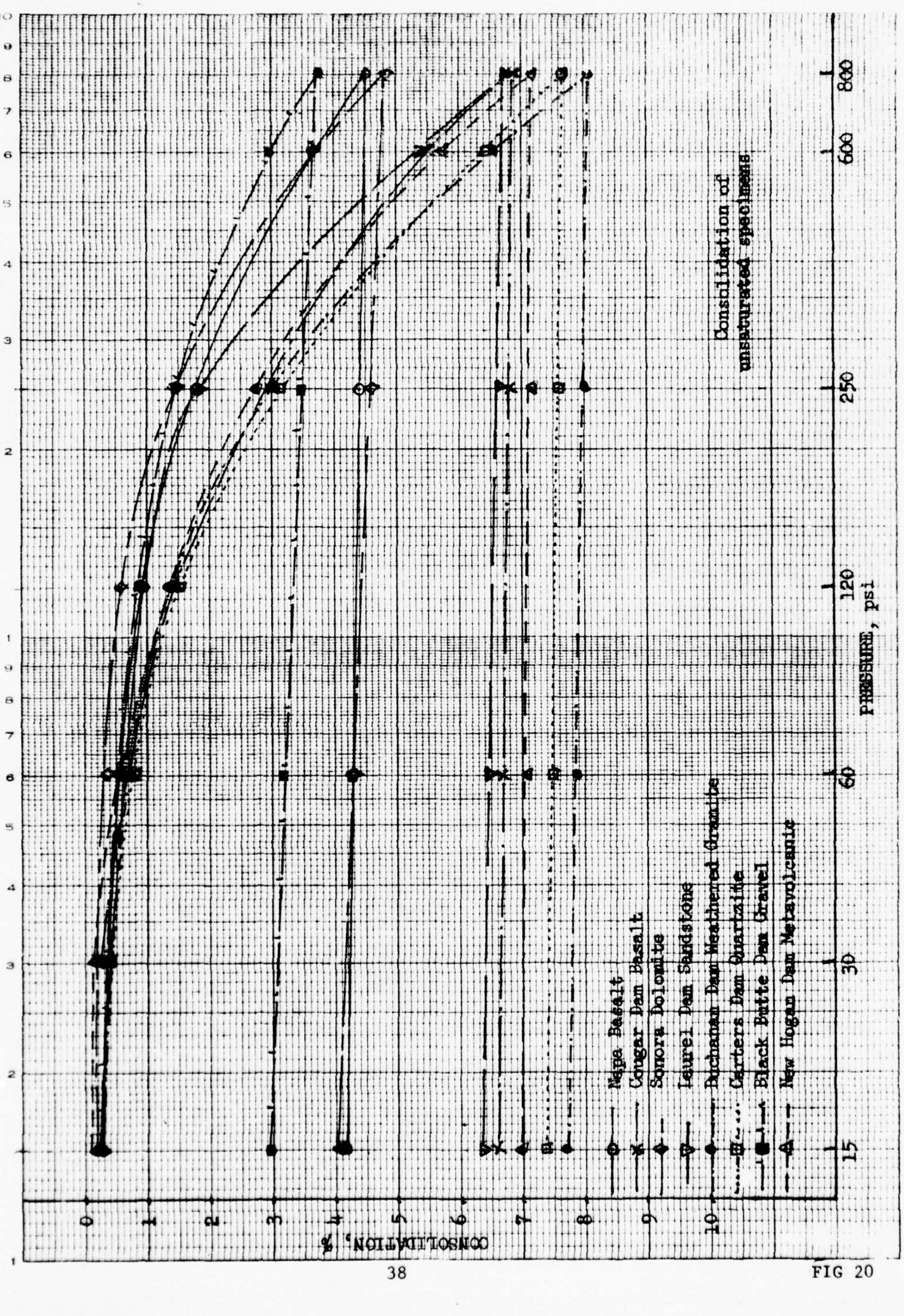
25. Consolidation

a. General. Consolidation results were evaluated by percent consolidation and compression index. Percent consolidation was defined as vertical deformation divided by initial specimen height. Compression index was calculated from the void ratio-pressure curves using the following equation:

$$C_c = \frac{e_1 - e_2}{\log_{10} p_2 - \log_{10} p_1}$$

Since the void ratio-pressure curves did not develop a straight line at higher pressures, the 250 and 800 psi pressures were used to calculate compression index. Void ratio-pressure plots and summary of test data are in Appendix A.

b. Consolidation. Greatest percent consolidation of the specimens tested in the dry condition at 800 psi was for Buchanan Granite and Carters Quartzite, 7.7 and 8.1 percent (Fig. 20). For saturated specimens, New Hogan metavolcanic, Buchanan granite and Cougar basalt exhibited the greatest consolidation, 10.7, 10.5, and 10.1 percent (Fig. 21). The least consolidation for both conditions were Napa basalt, Black Butte gravel, and Sonora dolomite, 4 to 5 percent dry and 5 to 6 percent saturated. Slopes of rebound curves were quite flat for all materials. For harder rocks, expansion between the final load, 800 psi, and the seating load was about $\frac{1}{2}$ percent for both saturated and dry tests. Soft rock specimens expanded slightly more than the hard rocks. For Black Butte gravel and Sonora dolomite, two of the materials which consolidated the least, rebound of one percent occurred.



Consolidation of
unsaturated specimens
CONSOLIDATION, %
PRESSURE, psi
15
30
60
120
250
600
800
0
1
2
3
4
5
6
7
8
9
10
Napa Basalt
Cougar Dam Basalt
Sonora Dolomite
Laurel Dam Sandstone
Buchanan Dam Weathered Granite
Carters Dam Quartzite
Black Butte Dam Gravel
New Hogan Dam Metavolcanic

FIG 20

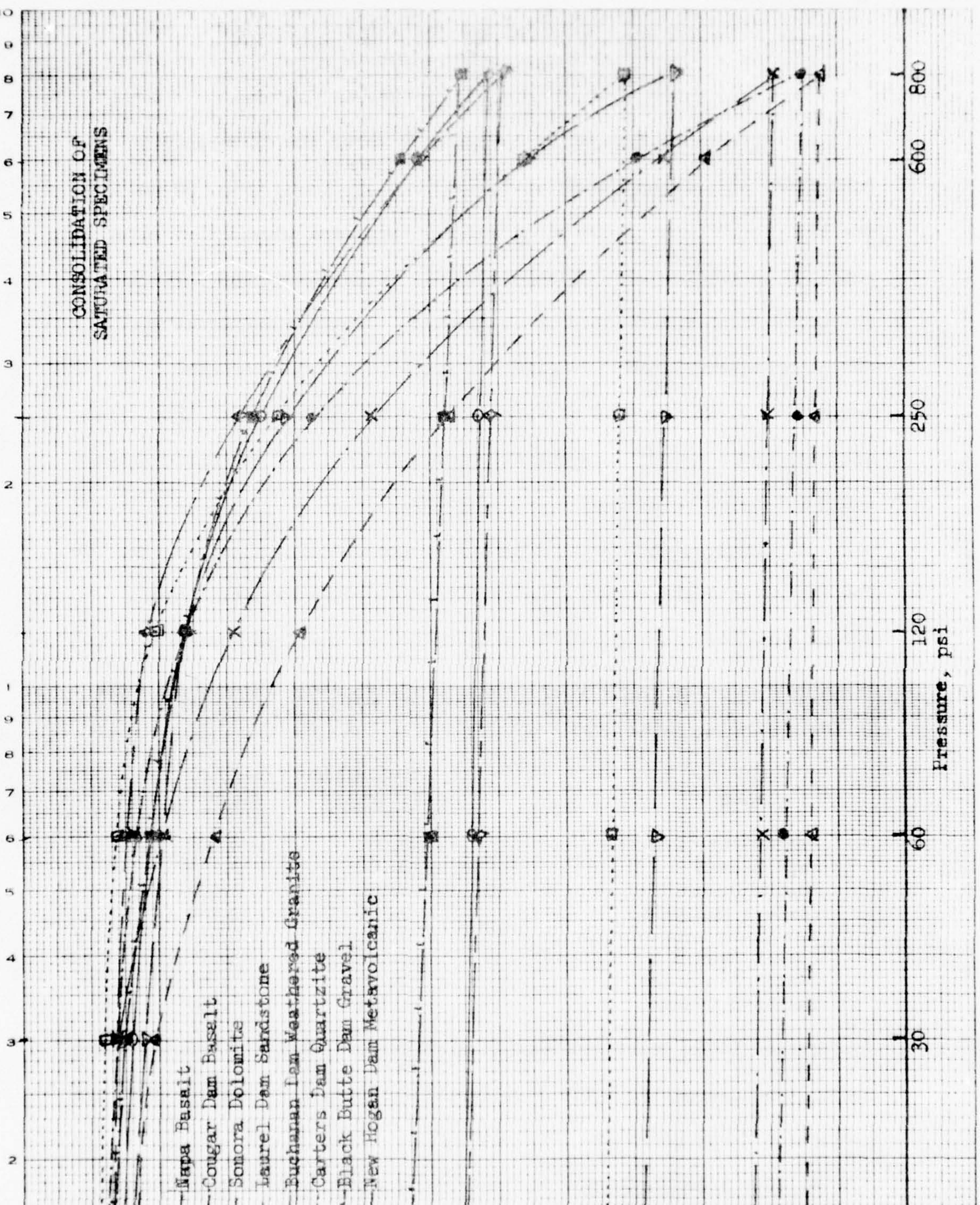

CONSOLIDATION OF
SATURATED SPECIMENS
Napa Basalt
Cougar Dam Basalt
Sonora Dolomite
Laurel Dam Sandstone
Buchanan Dam Weathered Granite
Carters Dam Quartzite
Black Butte Dam Gravel
New Hogan Dam Metavolcanic
CONSOLIDATION, %
Pressure, psi
15
30
60
120
250
600
800
SEMI-LOGARITHMIC
2 CYCLES X 20 DIVISIONS PER INCH

FIG 21

c. Effects of Inundation. Figure 22 shows the difference in consolidation between the saturated and dry specimens (Fig. 20 and 21). The difference between saturated and dry specimens showed that saturation resulted in greater consolidation for all materials except Carters quartzite which was relatively unaffected. Greatest increases were for New Hogan metavolcanic and Cougar basalt, 3.5 and 3.2 percent, respectively, an increase of approximately 50 percent. Smallest difference was for Carters quartzite, 0.2 percent. These differences could not be correlated with physical properties.

d. Compression Index. Greatest compression index values were for the saturated tests on Buchanan granite and Cougar basalt. Lowest values were for unsaturated Black Butte gravel and Napa basalt. Saturation increased the compression index for all materials as shown in the following table:

Rock	Compression Index, C_c Unsaturated	Saturated
Black Butte Gravel	0.058	0.082
Napa Basalt	0.068	0.092
Sonora Dolomite	0.090	0.104
Carters Quartzite	0.130	0.144
New Hogan Metavolcanic	0.134	0.163
Cougar Basalt	0.119	0.178
Laurel Sandstone	0.144	0.162
Buchanan Granite	0.141	0.204

Compression index decreased with increasing compressive strength, shape factor, and decreasing initial void ratio (Fig. 23). Abrasion loss and hardness did not correlate (Fig. 24).

e. Particle Breakage. All materials broke down to some degree under axial loading. Breakage was most severe for Laurel sandstone and Buchanan granite, but, the greatest increase in fines was for Sonora

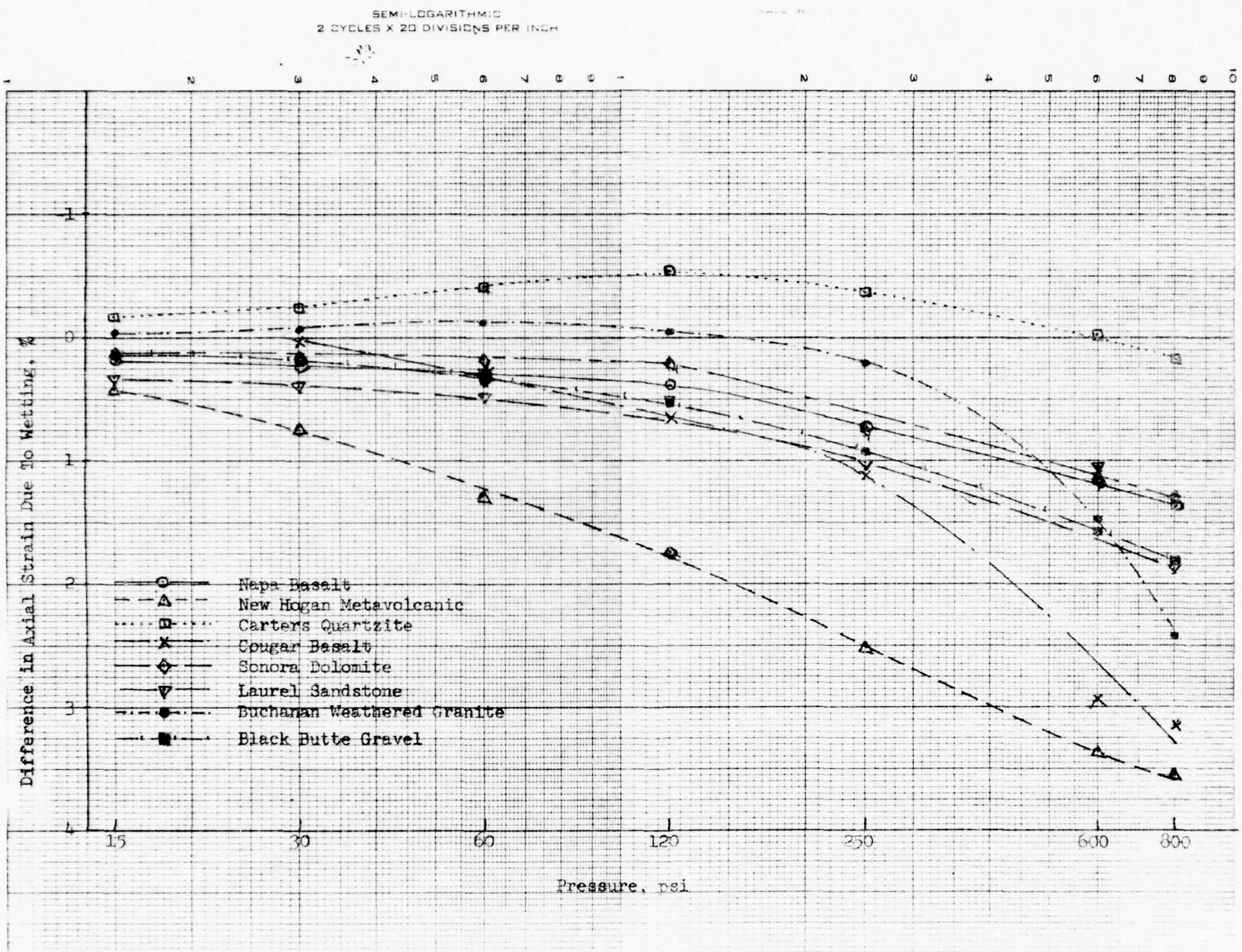

SEMI-LOGARITHMIC
2 CYCLES X 20 DIVISIONS PER INCH
Difference in Axial Strain Due To Wetting, %
-1
0
1
2
3
4
15
30
60
120
250
600
800
Pressure, psi
Napa Basalt
New Hogan Metavolcanic
Carters Quartzite
Cougar Basalt
Sonora Dolomite
Laurel Sandstone
Buchanan Weathered Granite
Black Butte Gravel

FIG 22

COMPRESSION INDEX
VS.
PHYSICAL PROPERTIES
of
Saturated Consolidation Specimens

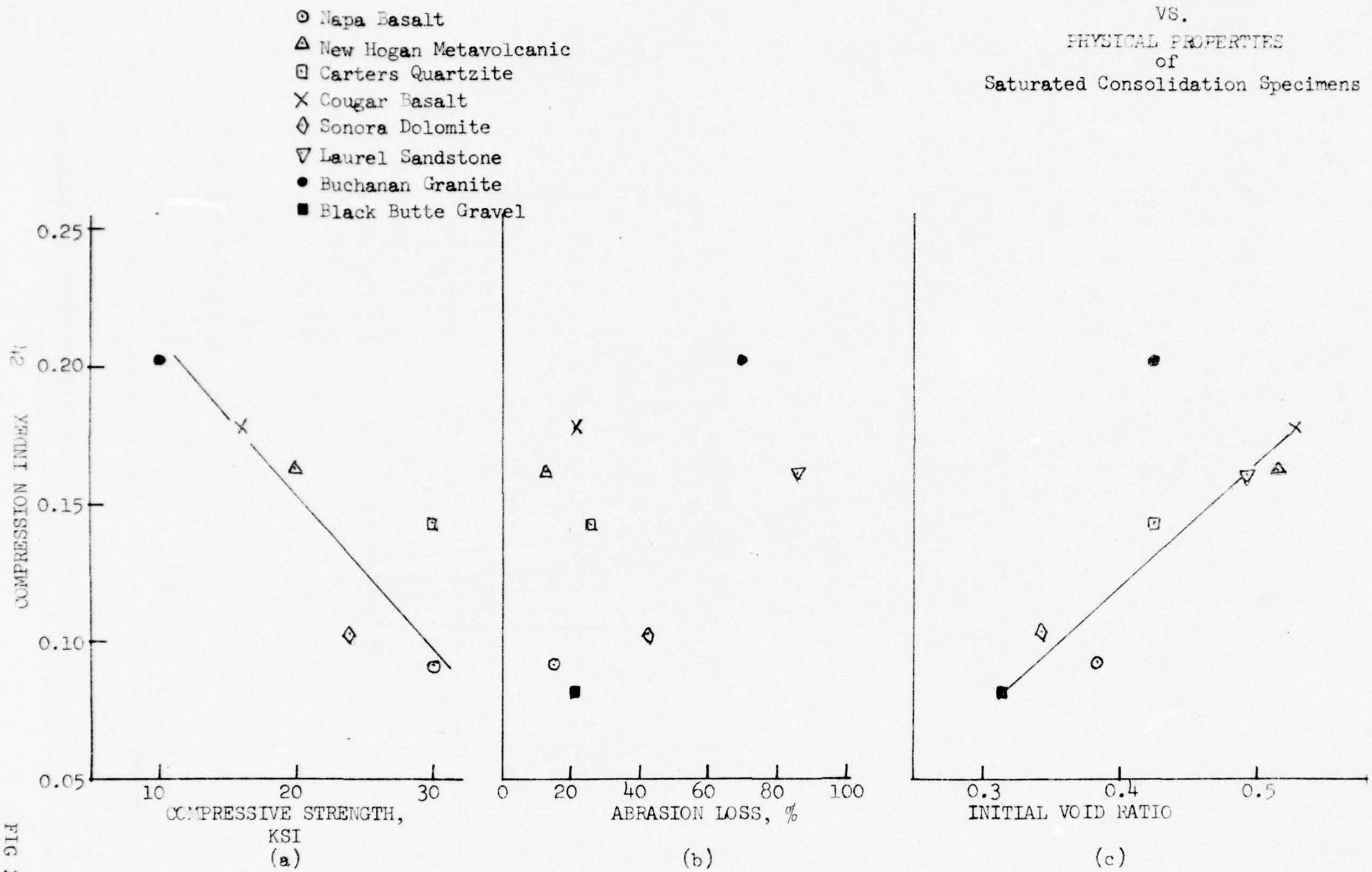


FIG 23

COMPRESSION INDEX
VS.
PHYSICAL PROPERTIES
of
Saturated Consolidation Specimens

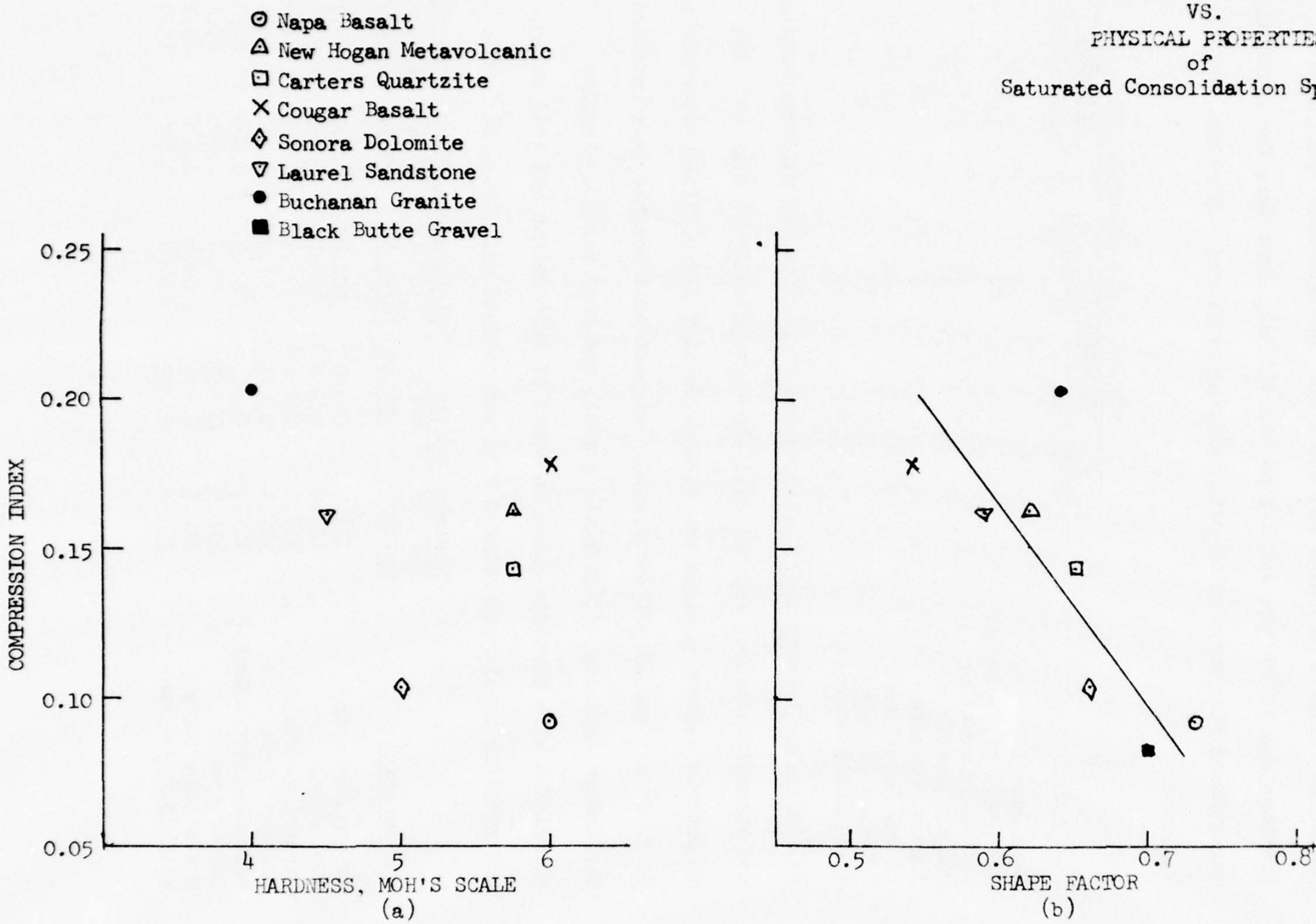


FIG 24

dolomite. Greater breakage was noted for the saturated specimens. Breakage due to 800 psi axial load was slightly less than for triaxial compression specimens at 60 psi confining pressure, summarized as follows:

Rock	Increase in % passing D_{10} Size: Consolidation, Unsaturated	Consolidation, Saturated	Triaxial $\sigma_3 = 60$ psi
Napa Basalt	4	4	3.5
New Hogan Metavolcanic	3	3	4
Carters Quartzite	3.5	5	7
Cougar Basalt	3	4.5	5.5
Sonora Dolomite	5	6.5	8
Laurel Sandstone	10.5	12.5	17.5
Buchanan Granite	7.5	12	14
Black Butte Gravel	3.5	5	-

26. Relative Density Test. The results of maximum and minimum densities are summarized below, and are also shown graphically on Fig. 25. The difference between maximum and minimum density for rockfill materials was 23 to 28 pcf and 15 pcf for gravel. Highest unit weights were obtained for Sonora dolomite, Black Butte gravel, and Napa basalt. Density correlated with particle shape in terms of unit weight and void ratio, and specific gravity correlated with unit weight only (Fig. 26 & 27).

Material	Maximum Density: Unit wt. lb/cu.ft.	Maximum Density: Void Ratio	Minimum Density: Unit wt. lb/cu.ft.	Minimum Density: Void Ratio	Density Difference lb/cu.ft.
Sonora Dolomite	131.7	0.350	107.0	0.662	24.7
Napa Basalt	129.0	0.384	103.7	0.721	25.3
Carters Quartzite	117.0	0.456	95.1	0.791	21.9
Buchanan Granite	117.3	0.431	97.0	0.731	20.1
New Hogan Metavolcanic	117.3	0.511	95.3	0.859	22.0
Cougar Basalt	111.9	0.528	91.2	0.875	20.7
Laurel Sandstone	110.7	0.494	85.6	0.932	25.1
Black Butte Gravel	131.6	0.299	116.6	0.446	15.0

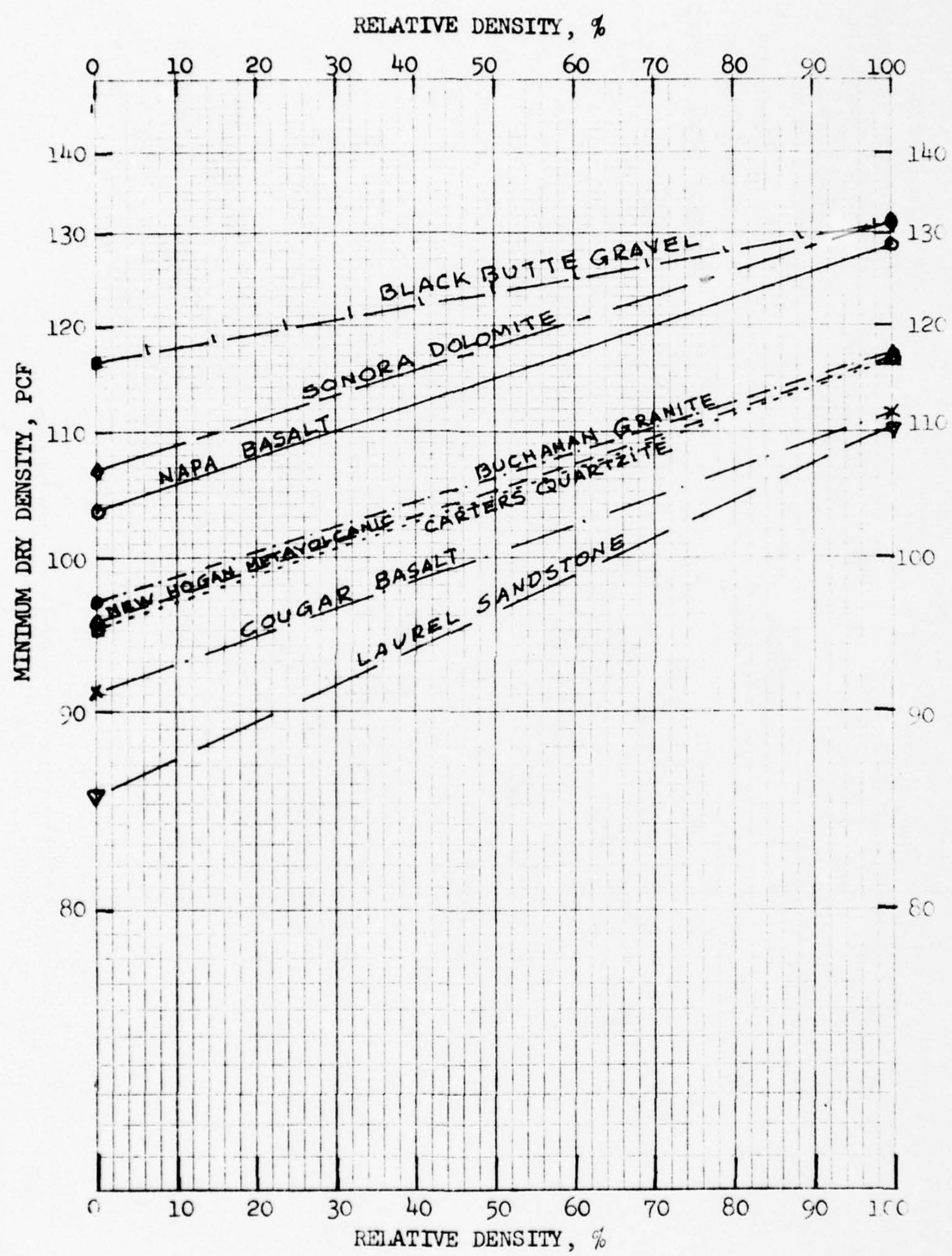
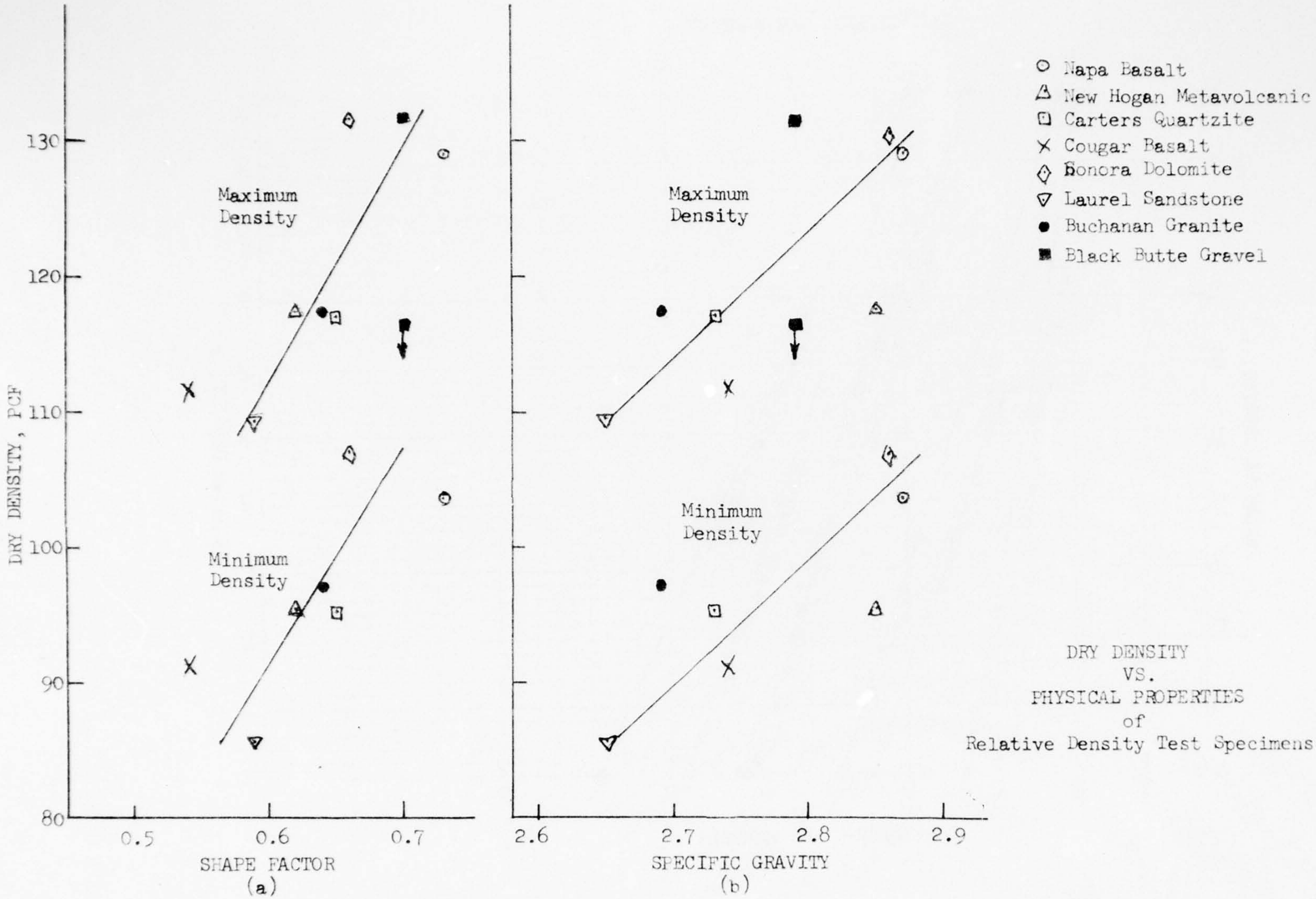
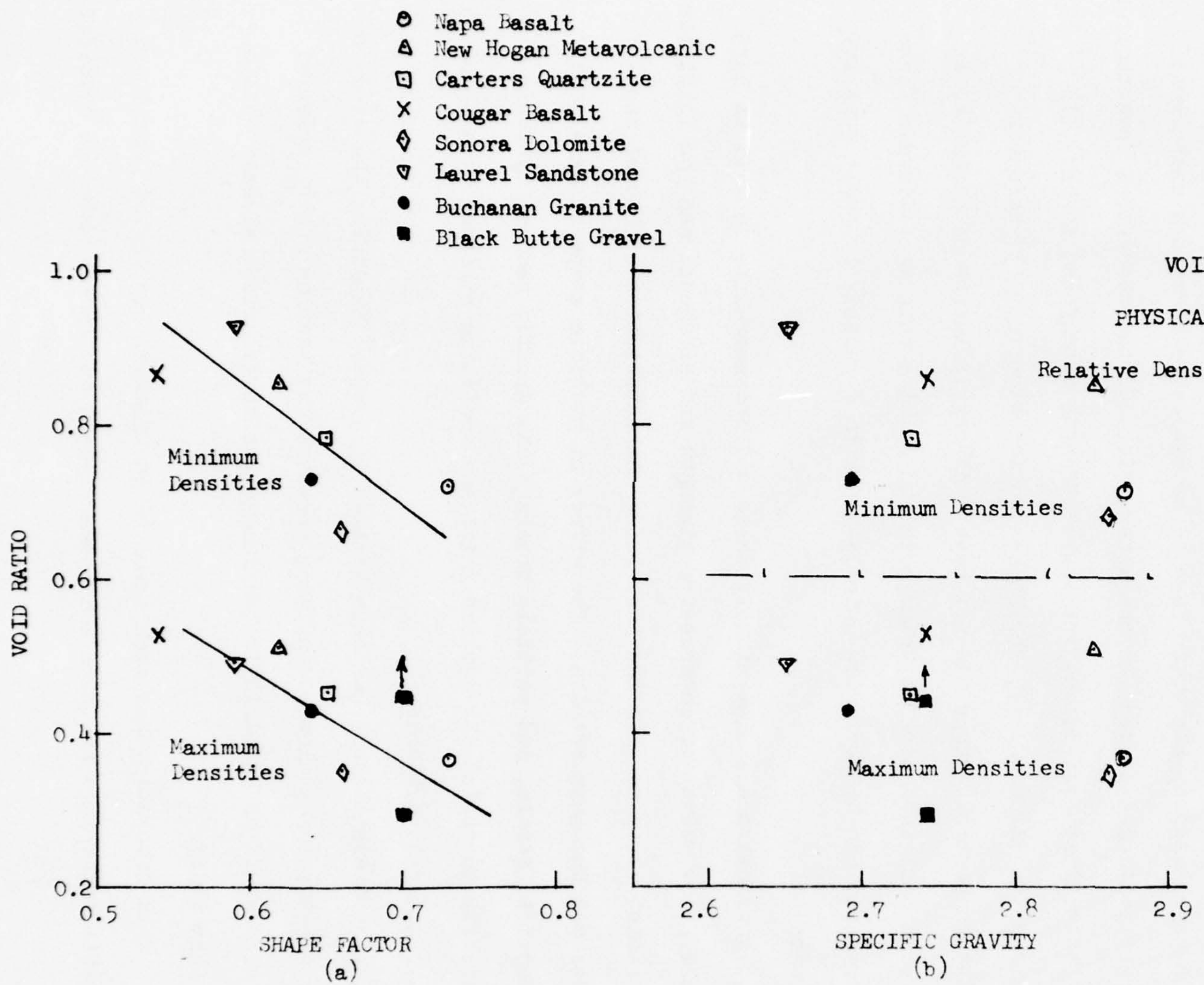

RELATIVE DENSITY, %
0
10
20
30
40
50
60
70
80
90
100
140
130
120
110
100
90
80
MINIMUM DRY DENSITY, PCF
MAXIMUM DRY DENSITY, PCF
BLACK BUTTE GRAVEL
SONORA DOLOMITE
NAPA BASALT
BUCHANAN GRANITE
NEW HOGAN METAVOLCANIC
CARTERS QUARTZITE
COUGAR BASALT
LAUREL SANDSTONE
RELATIVE DENSITY, %

FIG 25



DRY DENSITY
VS.
PHYSICAL PROPERTIES
of
Relative Density Test Specimens

FIG 26



VOID RATIO
VS.
PHYSICAL PROPERTIES
of
Relative Density Test Specimens

FIG 27

CONCLUSIONS

27. Triaxial Compression Test. No single physical property of rockfill material can reveal its shear characteristics, but each property investigated can contribute toward a realistic estimate. The importance of each physical property would have to be evaluated as to its usefulness for estimating a particular characteristic. Of the properties investigated, the three that best define intrinsic strength were found to be: (1) Compressive strength, (2) resistance to abrasion, and (3) hardness. Although particle shape did not have a strong influence on strength, it was the best indicator of volumetric and axial strain at failure. These four tests can be performed quickly and with a relatively small quantity of material.

28. Physical properties of soft rocks did not correlate as well as hard rocks. Low values of compressive strength and hardness, and the inability to resist abrasion were the overriding characteristics of Laurel sandstone and Buchanan granite. The effect of particle shape on axial and volumetric strain, and particle breakage was greatly reduced by their inability to resist the applied axial and confining stresses because of their inherent softness.

29. The present study has been limited in scope. Expanding the study to include testing at lower confining pressure and testing other varieties of rock would be valuable in confirming the correlations already obtained in this study.

30. This laboratory has been involved in triaxial testing of gravel and rockfill materials for more than twenty years but rarely were the physical

properties determined, and, in many instances both high and low density test series were not performed. However, New Melones Dam rockfill was recently tested at two densities as well as for abrasion loss and compressive strength. By utilizing the values of these two properties, the average angle of internal friction at 60 psi confining pressure was estimated to be 48 degrees. The actual test value at 100 percent relative density was 47 degrees. This material was a metavolcanic rock with a quarry-run gradation similar to that shown in Figure 1.

31. Consolidation Test. Consolidation at 800 psi varied from 3.7 to 8.1 percent for dry tests and 5.5 to 10.7 percent for saturated tests, a difference of about two percent. Variation in the magnitude of change due to wetting varied considerably between rock types. Carters quartzite was relatively unaffected, but notable increases were recorded for Cougar basalt and New Hogan metavolcanic. Since the difference did not correlate with any of the physical properties investigated, they may be due to the inherent friction characteristics of the principal minerals or to surface texture which was not investigated. Therefore, the sensitivity of a material to wetting could be determined only by some form of consolidation test. The properties that correlated with compression index were: (1) shape factor, (2) compressive strength, and (3) initial void ratio.

32. Particle Breakage. Breakage was shown to be related principally to confining and axial stresses, abrasion loss, and hardness. Factors which had less effect were particle shape, compressive strength, and water content. Consolidation tests showed that as the quality of the rock decreased, breakage due to wetting increased. Breakage for triaxial testing was considerably greater than for consolidation testing. Isotropic

consolidation resulted in more breakage than one-dimensional consolidation because of greater volumetric strain caused by the confining pressure. In addition particle breakage was increased because of greater axial strain, 15-30 percent compared to 4-11 percent for the consolidation testing. Density was not a major factor in particle breakage.

APPENDIX A

TEST PLATES

DEPARTMENT OF THE ARMY
SOUTH PACIFIC DIVISION LABORATORY, CORPS OF ENGINEERS
SAUSALITO, CALIFORNIA 94965

TRIAXIAL COMPRESSION TEST DATA
ES 526 NATURAL GRADATION

NAPA BASALT

Test No.	Compaction Test		Specimen Test Conditions									Shear Data				
			Before Consolidation				After Consolidation									
	Maximum Density pcf	Minimum Density pcf	(1) Dens. pcf	(2) Dens. pcf	(3) Void Ratio	(4) RD %	Dens. pcf	Void Ratio	RD %	Water Content %	Sat. %	σ_3 psi	Maximum Deviator Stress psi	Strain @ Maximum $\sigma_1 - \sigma_3$	Void Ratio @ Failure	ϕ Degrees
156	129.0	103.7	128.3	129.8	.375	98	131.2	.361	102	12.6	100	60	384	12.1	.335	49.7
157			128.6	129.8	.375	98	132.3	.349	106	11.3	93	125	607	15.8	.303	45.1
158			128.2	129.8	.375	98	132.9	.343	107	11.2	94	300	1162	15.9	.253	41.3
159			128.5	130.3	.369	100	136.5	.308	117	10.0	93	400	1464	18.1	.215	40.2
160	129.0	103.7	103.6	108.3	.698	21	111.8	.596	31	20.3	97	60	260	30.4	.421	43.2
161			103.6	106.6	.673	14	112.8	.582	39	19.5	96	125	443	27.1	.420	39.7
162			103.9	106.9	.669	15	116.8	.528	55	16.2	88	300	860	28.7	.305	36.1
163			103.7	106.3	.676	13	120.9	.476	70	15.6	94	400	1122	*29.3	.251	35.7

(1) By vibration
(2) After evacuation at 14 psi
(3) " " " "
(4) Computed from maximum value in Column (2)

Note:
a. Coefficient of uniformity - 9.0
b. Coefficient of curvature - 1.5
c. Specimen diameter - 12.0 inches
d. Specimen height - 27.6 inches

*Did not peak.

DEPARTMENT OF THE ARMY
SOUTH PACIFIC DIVISION LABORATORY, CORPS OF ENGINEERS
SAUSALITO, CALIFORNIA 94965

TRIAXIAL COMPRESSION TEST DATA
ES 526 NATURAL GRADATION

NEW HOGAN DAM METAVOLCANIC

	Compaction Test		Specimen Test Conditions									Shear Data				
			Before Consolidation				After Consolidation									
Test No.	Maximum Density pcf	Minimum Density pcf	(1) Dens. pcf	(2) Dens. pcf	(3) Void Ratio	(4) RD %	Dens. pcf	Void Ratio	RD %	Water Content %	Sat. %	σ_3 psi	Maximum Deviator Stress psi	Strain @ Maximum $\sigma_1-\sigma_3$	Void Ratio @ Failure	ϕ Degrees
164	117.3	95.3	117.1	119.6	.482	99	121.7	.456	106	-	-	60	327	17.9	.395	47.0
165			117.2	119.0	.487	98	123.9	.431	112	14.2	94	125	581	24.1	.318	44.4
166			116.9	119.0	.489	98	128.6	.378	126	-	-	300	1074	24.3	.241	39.9
167			117.2	119.9	.478	100	131.2	.350	134	9.9	80	400	1377	24.6	.206	39.4
168	117.3	95.3	96.0	99.5	.781	21	103.8	.708	40	22.0	88	60	216	28.1	.500	40.0
169			97.1	101.0	.754	28	108.9	.627	61	19.7	89	125	372	29.1	.406	36.8
170			96.9	100.0	.772	23	113.8	.558	79	15.1	78	300	768	*29.4	.307	34.2
171			97.2	101.1	.753	28	115.6	.532	86	18.4	98	400	1051	*28.2	.306	34.6

(1) By vibration
(2) After evacuation at 14 psi
(3) " " " "
(4) Computed from maximum value in Column (2)

Note:
a. Coefficient of uniformity - 9.0
b. Coefficient of curvature - 1.5
c. Specimen diameter - 12.0 inches
d. Specimen height - 27.6 inches

*Did not peak.

SPDL

DEPARTMENT OF THE ARMY
SOUTH PACIFIC DIVISION LABORATORY, CORPS OF ENGINEERS
SAUSALITO, CALIFORNIA 94965

TRIAXIAL COMPRESSION TEST DATA
ES 526 NATURAL GRADATION

CARTERS DAM QUARTZITE

	Compaction Test		Specimen Test Conditions										Shear Data			
			Before Consolidation				After Consolidation									
Test No.	Maximum Density pcf	Minimum Density pcf	(1) Dens. pcf	(2) Dens. pcf	(3) Void Ratio	(4) RD %	Dens. pcf	Void Ratio	RD %	Water Content %	Sat. %	σ_3 psi	Maximum Deviator Stress psi	Strain @ Maximum $\sigma_1 - \sigma_3$	Void Ratio @ Failure	ϕ Degrees
180	117.0	95.1	119.3	120.6	.413	96	123.0	.385	104	12.4	88	60	328	14.6	.288	47.1
181			119.5	120.7	.412	97	124.1	.372	107	12.3	90	125	563	16.6	.277	43.8
182			119.5	121.7	.399	100	129.2	.319	120	11.4	98	300	1147	21.9	.205	41.0
183			118.7	121.4	.403	99	130.8	.303	124	10.7	96	400	1352	21.7	.193	38.9
184	117.0	95.1	95.9	98.3	.733	15	101.9	.672	31	22.5	91	60	206	30.0	.436	39.1
185			96.0	99.4	.714	20	106.9	.594	50	21.1	97	125	419	*31.9	.304	38.8
186			96.4	101.2	.684	27	117.3	.452	86	14.0	85	300	915	*28.9	.244	37.1
187			96.4	100.9	.688	26	118.3	.440	90	16.0	99	400	1122	*28.3	.246	35.7

(1) By vibration
(2) After evacuation at 14 psi
(3) " " " "
(4) Computed from maximum value in Column (2)

Note:
a. Coefficient of uniformity - 9.0
b. Coefficient of curvature - 1.5
c. Specimen diameter - 12.0 inches
d. Specimen height - 27.6 inches

*Did not peak.

DEPARTMENT OF THE ARMY
SOUTH PACIFIC DIVISION LABORATORY, CORPS OF ENGINEERS
SAUSALITO, CALIFORNIA 94965

TRIAXIAL COMPRESSION TEST DATA
ES 526 NATURAL GRADATION

COUGAR DAM BASALT

Test No.	Compaction Test		Specimen Test Conditions									Shear Data				
			Before Consolidation				After Consolidation									
	Maximum Density pcf	Minimum Density pcf	(1) Dens. pcf	(2) Dens. pcf	(3) Void Ratio	(4) RD %	Dens. pcf	Void Ratio	RD %	Water Content %	Sat. %	σ_3 psi	Maximum Deviator Stress psi	Strain @ Maximum 1-3	Void Ratio @ Failure	ϕ Degrees
172	111.9	91.2	112.3	114.6	0.492	100	116.3	0.471	106	15.9	93	60	310	19.8	0.442	46.1
233			112.3	113.8	0.501	98	118.2	0.444	113	16.0	98	125	540	23.0	0.314	43.1
174			112.4	113.7	0.504	97	121.8	0.403	123	-	-	300	993	25.9	0.267	38.5
175			112.8	114.2	0.497	99	124.6	0.372	131	13.1	96	400	1302	24.5	0.231	38.3
176	111.9	91.2	92.4	95.8	0.785	23	97.1	0.761	30	23.8	86	60	233	27.3	0.553	41.3
177			92.5	97.4	0.756	31	105.5	0.621	66	21.8	96	125	457	28.7	0.383	40.2
178			92.5	98.3	0.739	35	111.0	0.540	88	18.5	94	300	841	28.8*	0.311	35.7
179			92.3	95.7	0.787	23	113.2	0.509	96	17.7	95	400	1095	28.8*		35.3

(1) By vibration
(2) After evacuation at 14 psi
(3) " " " "
(4) Computed from maximum value in Column (2)

Note:
a. Coefficient of uniformity - 9.0
b. Coefficient of curvature - 1.5
c. Specimen diameter - 12.0 inches
d. Specimen height - 27.6 inches

*No Peak

DEPARTMENT OF THE ARMY
SOUTH PACIFIC DIVISION LABORATORY, CORPS OF ENGINEERS
SAUSALITO, CALIFORNIA 94965

TRIAXIAL COMPRESSION TEST DATA
ES 526 NATURAL GRADATION

SONORA DOLOMITE

Test No.	Compaction Test: Maximum Density pcf	Compaction Test: Minimum Density pcf	Specimen Test Conditions, Before Consolidation: (1) Dens. pcf	(2) Dens. pcf	(3) Void Ratio	(4) RD %	After Consolidation: Dens. pcf	Void Ratio	RD %	Water Content %	Sat. %	Shear Data: σ_3 psi	Maximum Deviator Stress psi	Strain @ Maximum 1-3	Void Ratio @ Failure	ϕ Degrees
238	131.7	107.0	132.8	134.0	.327	100	135.6	.311	101	10.7	98	60	276	14.6	.275	44.8
239			132.7	134.0	.327	100	136.1	.306	106	10.6	98	125	498	14.9	.218	41.8
240			132.7	133.4	.333	98	139.3	.277	115	9.5	98	300	994	16.9	.130	38.6
241			132.7	133.8	.330	99	141.9	.253	122	8.7	98	400	1331	17.9	.162	3[illegible].6
242			112.8	116.7	.524	41	121.3	.466	59	16.0	98	60	244	24.8	.318	42.1
243			112.9	115.8	.536	38	123.7	.437	67	15.5	100	125	427	*29.9	.246	39.1
244			113.0	116.7	.524	41	130.2	.366	88	12.9	100	300	886	29.1	.180	36.6
245			113.0	115.1	.545	35	131.0	.358	91	12.3	98	400	1118	*27.5	.178	35.6

(1) By vibration
(2) After evacuation at 14 psi
(3) " " " "
(4) Computed from maximum value in Column (2)

Note:
a. Coefficient of uniformity - 9.0
b. Coefficient of curvature - 1.5
c. Specimen diameter - 12.0 inches
d. Specimen height - 27.6 inches

*Did not peak.

DEPARTMENT OF THE ARMY
SOUTH PACIFIC DIVISION LABORATORY, CORPS OF ENGINEERS
SAUSALITO, CALIFORNIA 94965

TRIAXIAL COMPRESSION TEST DATA
ES 526 NATURAL GRADATION

LAUREL DAM SANDSTONE

Test No.	Compaction Test: Maximum Density pcf	Compaction Test: Minimum Density pcf	Specimen Test Conditions, Before Consolidation: (1) Dens. pcf	(2) Dens. pcf	(3) Void Ratio	(4) RD %	After Consolidation: Dens. pcf	Void Ratio	RD %	Water Content %	Sat. %	σ_3 psi	Shear Data: Maximum Deviator Stress psi	Strain @ Maximum $\sigma_1-\sigma_3$	Void Ratio @ Failure	ϕ Degrees
269	110.7	86.5	110.9	112.3	0.468	100	113.9	0.447	105	17.0	100	60	241	26.1	0.350	42.0
266			110.1	112.3	0.468	100	113.6	0.450	104	16.5	98	60	237	22.1	0.359	41.6
189			110.9	111.7	0.475	98	114.8	0.435	107	15.3	96	125	365	18.1	0.335	41.1
190			109.4	110.5	0.491	94	116.0	0.420	111	14.8	93	300	987	17.3	0.321	38.5
267			110.7	111.1	0.483	96	115.9	0.422	110	15.4	97	300	983	20.5	0.299	38.4
191			110.9	111.7	0.475	98	118.4	0.392	117	13.9	94	400	1288	17.1	0.295	38.1
270	110.7	86.51	86.5	89.5	0.840	15	93.7	0.758	33	22.7	79	60	190	30.0*	0.515	37.8
193			86.5	90.8	0.814	21	98.2	0.677	52	22.6	88	125	373	30.3	0.400	36.8
194			86.9	90.6	0.819	20	100.8	0.634	62	17.7	74	300	821	23.6*	0.470	35.3
195			87.3	92.5	0.781	28	110.0	0.501	92	18.2	96	400	1075	23.8	0.342	35.0

(1) By vibration
(2) After evacuation at 14 psi
(3) " " " "
(4) Computed from maximum value in Column (2)

Note:
a. Coefficient of uniformity - 9.0
b. Coefficient of curvature - 1.5
c. Specimen diameter - 12.0 inches
d. Specimen height - 27.6 inches

* No Peak

DEPARTMENT OF THE ARMY
SOUTH PACIFIC DIVISION LABORATORY, CORPS OF ENGINEERS
SAUSALITO, CALIFORNIA 94965

TRIAXIAL COMPRESSION TEST DATA
ES 526 NATURAL GRADATION

BUCHANAN DAM WEATHERED GRANITE

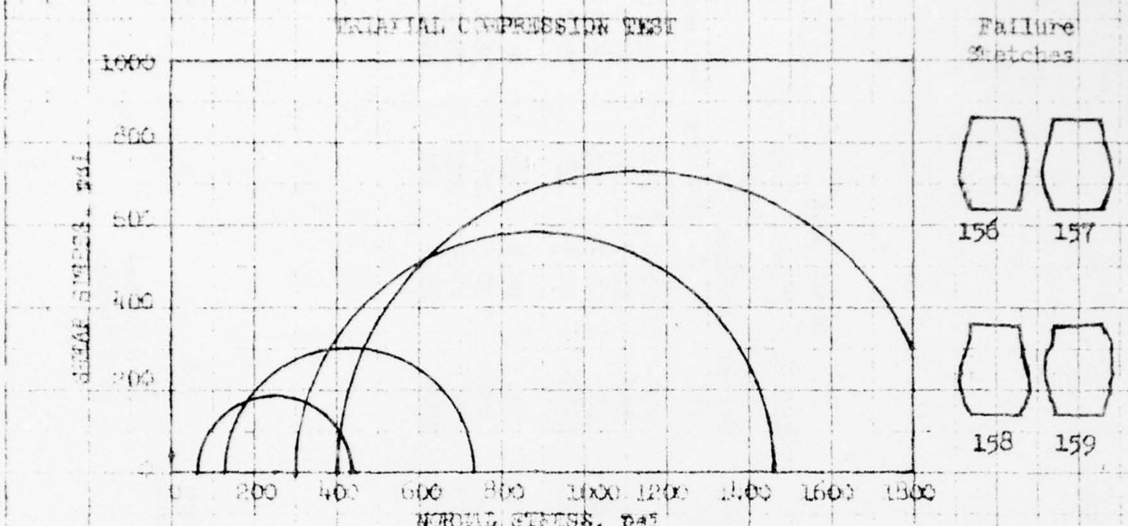
Test No.	Compaction Test: Maximum Density pcf	Compaction Test: Minimum Density pcf	Specimen Test Conditions, Before Consolidation: (1) Dens. pcf	(2) Dens. pcf	(3) Void Ratio	(4) RD %	After Consolidation: Dens. pcf	Void Ratio	RD %	Water Content %	Sat. %	σ_3 psi	Shear Data: Maximum Deviator Stress psi	Strain @ Maximum $\sigma_1 - \sigma_3$	Void Ratio @ Failure	ϕ Degrees
148	117.3	97.0	118.2	120.3	.396	100	121.9	.378	105	13.1	93	60	212	21.0	.294	39.7
149			118.3	119.7	.402	98	123.0	.365	109	13.0	96	125	398	26.7	.247	37.9
150			118.0	119.7	.402	98	127.6	.316	124	10.9	93	300	882	21.3	.206	36.5
151			118.0	119.7	.402	98	130.8	.293	131	10.7	100	450	1358	20.7	.185	37.0
152	117.3	97.0	98.1	103.7	.619	33	110.6	.518	63	-	-	60	188	25.4	.320	37.6
153			97.9	102.3	.642	26	113.5	.479	75	13.7	75	125	362	*30.3	.286	36.3
154			98.2	103.9	.616	34	121.8	.378	105	13.0	93	300	859	27.4	.232	36.0
155			98.3	104.6	.604	38	128.3	.308	126	9.4	82	450	1269	25.7	.191	35.8

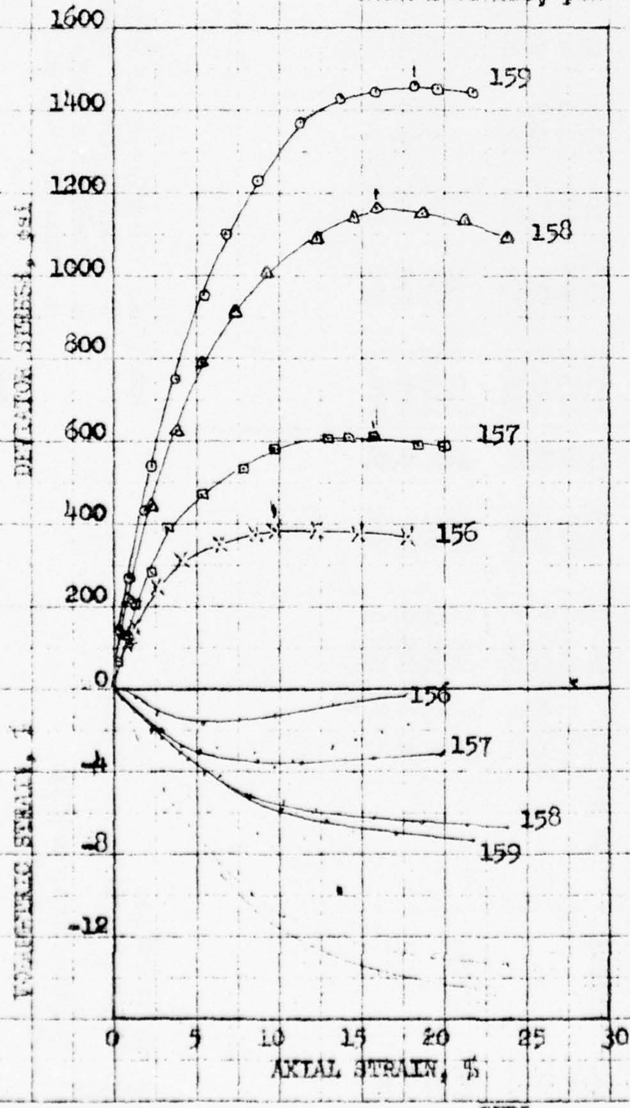
(1) By vibration
(2) After evacuation at 14 psi
(3) " " " "
(4) Computed from maximum value in Column (2)

Note:
a. Coefficient of uniformity - 9.0
b. Coefficient of curvature - 1.5
c. Specimen diameter - 12.0 inches
d. Specimen height - 27.6 inches

*Did not peak.

SPD





Test No.	σ_3 psi	Dry Density, pcf Initial	Test
156	60	128.1	131.2
157	125	128.6	132.3
158	300	128.2	132.9
159	400	128.5	136.5

SHEAR STRENGTH OF ROCK FILL

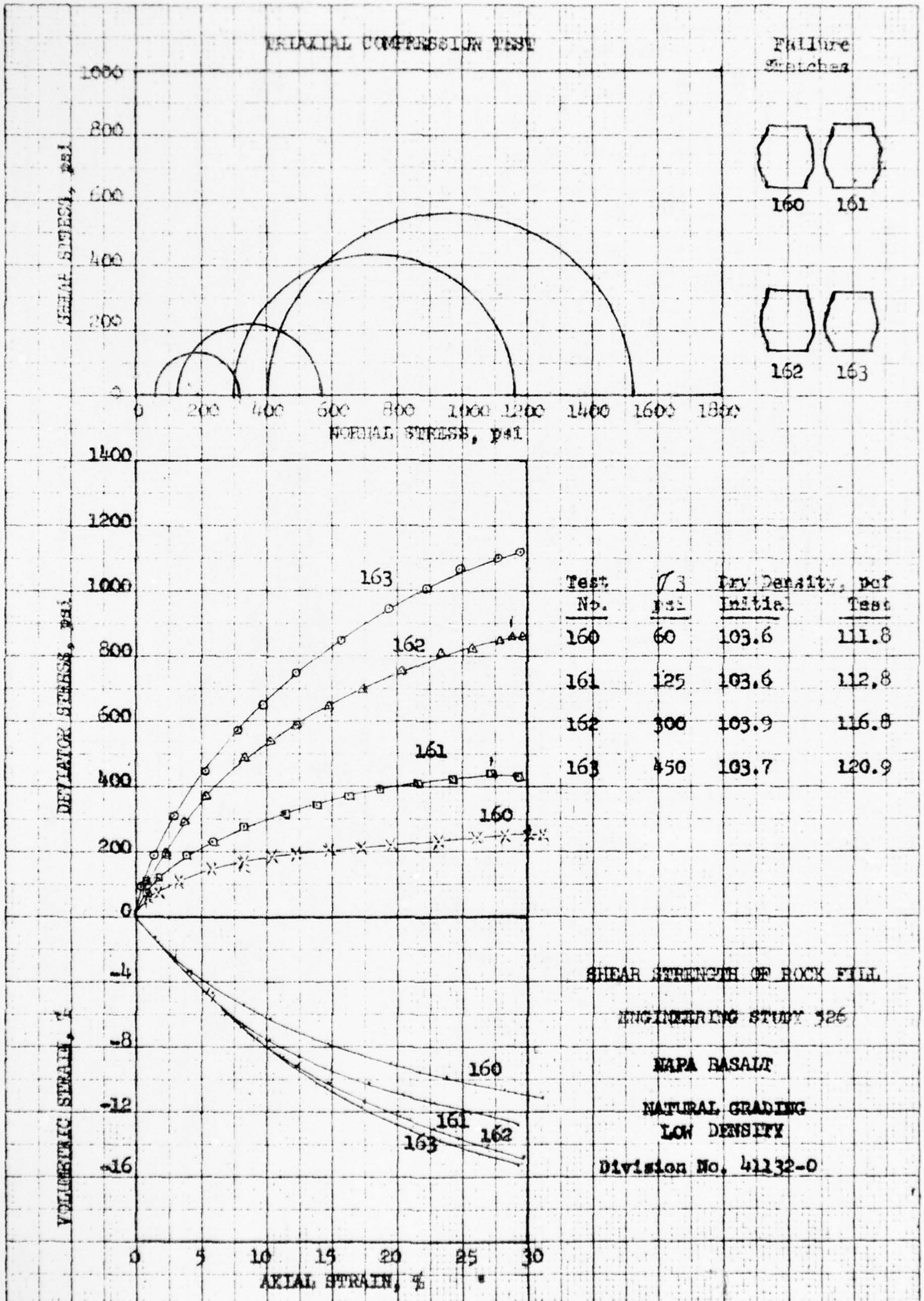
ENGINEERING STUDY [illegible]

NAPA BASALT

NATURAL GRADING
HIGH DENSITY

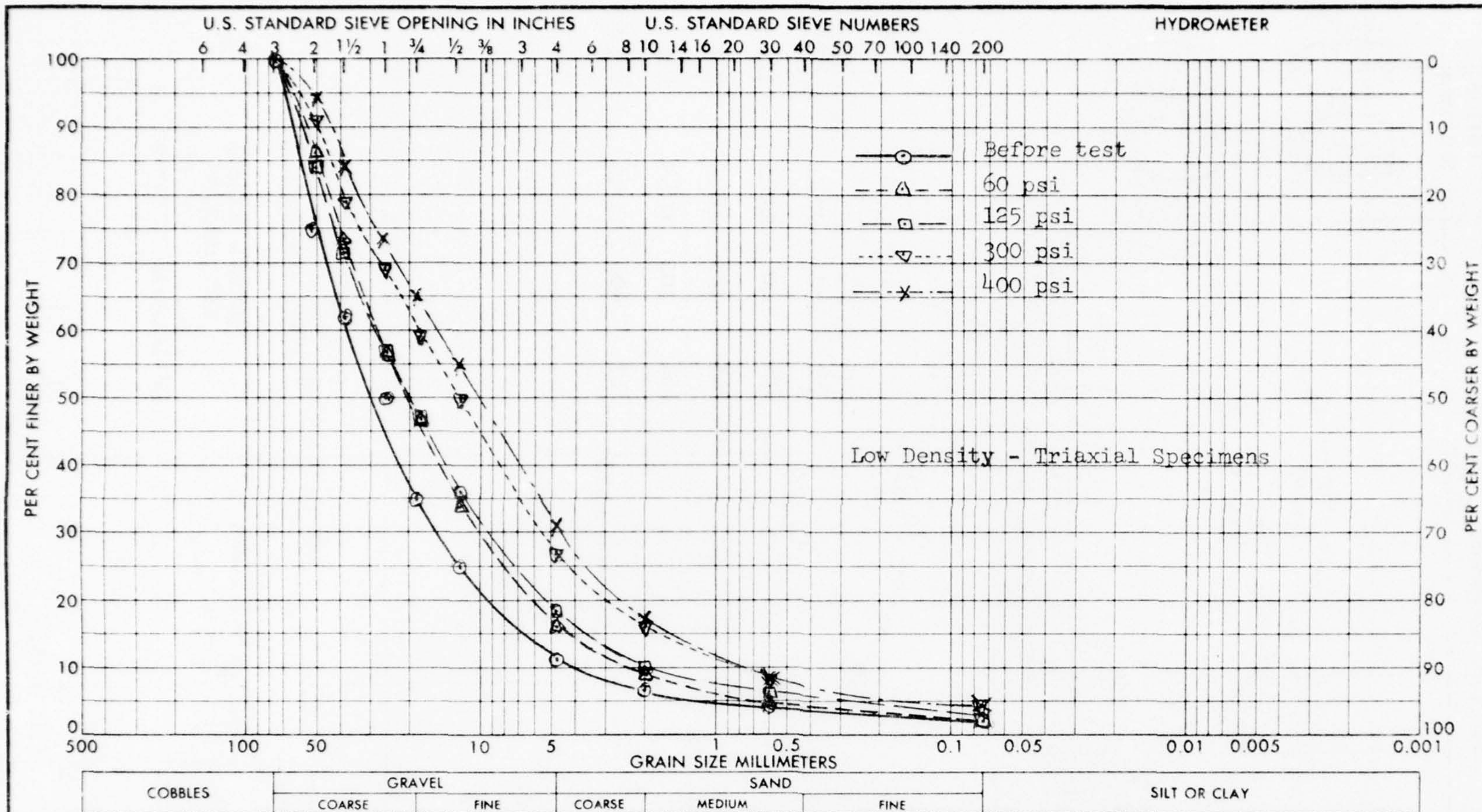
Division No. 41132-0

SPDL



TRIAXIAL COMPRESSION TEST
Failure Sketches
160
161
162
163
SHEAR STRESS, psi
NORMAL STRESS, psi
DEVIATOR STRESS, psi
VOLUMETRIC STRAIN, %
AXIAL STRAIN, %
Test No. | σ3 psi | Dry Density, pcf Initial | Test
160 | 60 | 103.6 | 111.8
161 | 125 | 103.6 | 112.8
162 | 300 | 103.9 | 116.8
163 | 450 | 103.7 | 120.9
SHEAR STRENGTH OF ROCK FILL
ENGINEERING STUDY
NAPA BASALT
NATURAL GRADING
LOW DENSITY
Division No. 41132-0

SPDL



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

PROJECT ES-526

Shear Strength of Rock Fill

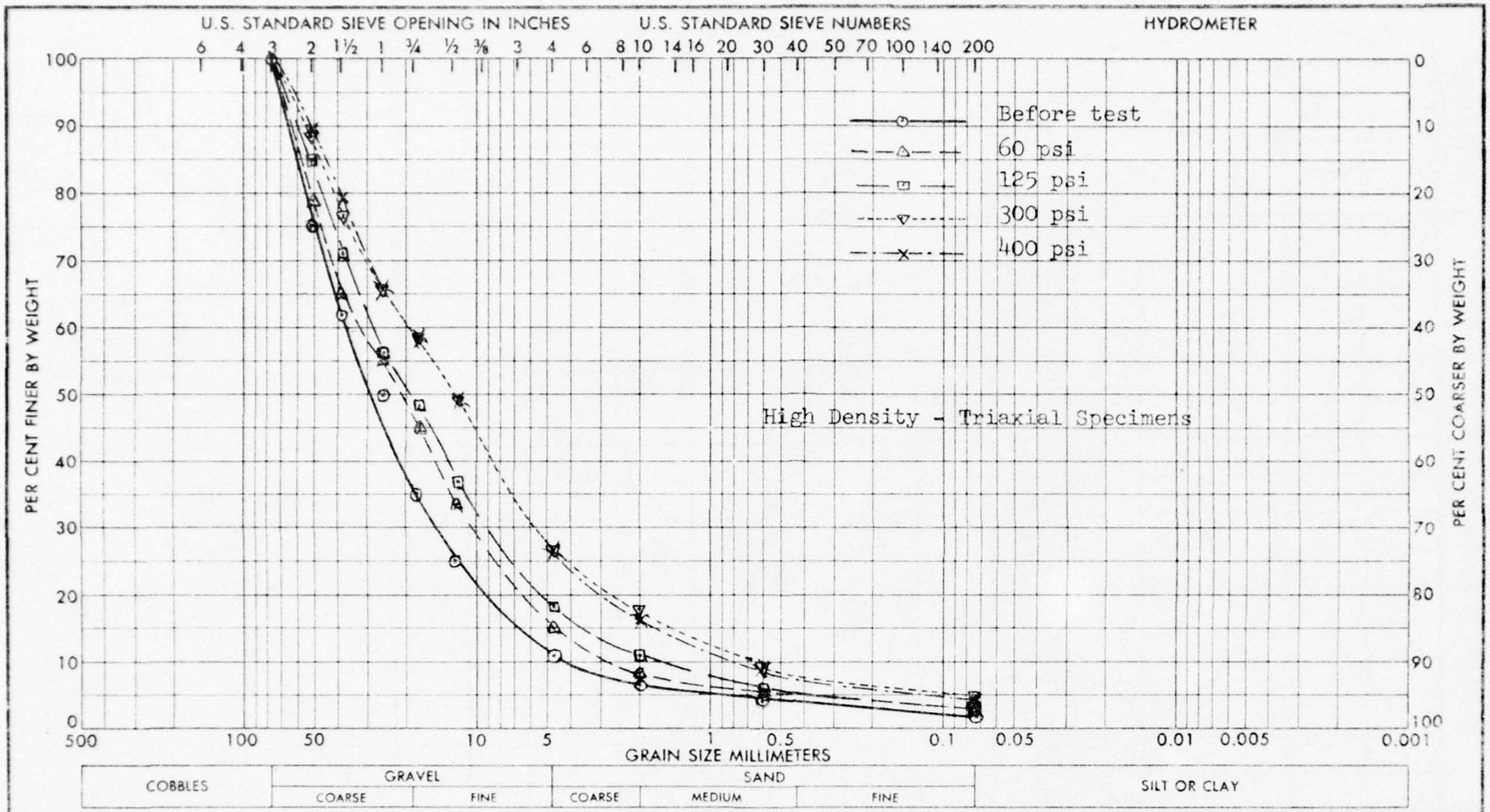
AREA Napa Basalt

BORING NO.

DATE

GRADATION CURVES

ENG FORM 2087 1 MAY 63 REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE. *(TRANSLUCENT)* SPDL



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

PROJECT ES-526

Shear Strength of Rock Fill

AREA Napa Basalt

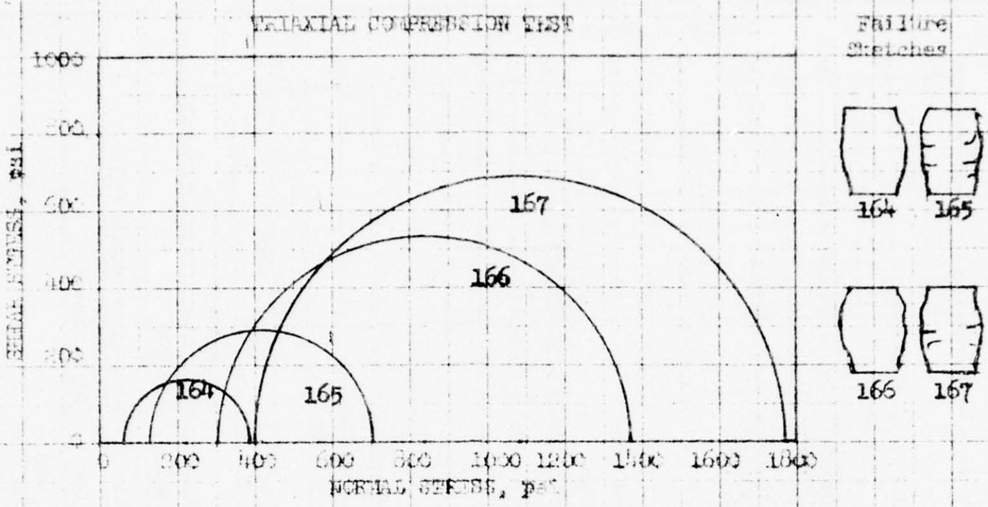
BORING NO. Natural Gradation

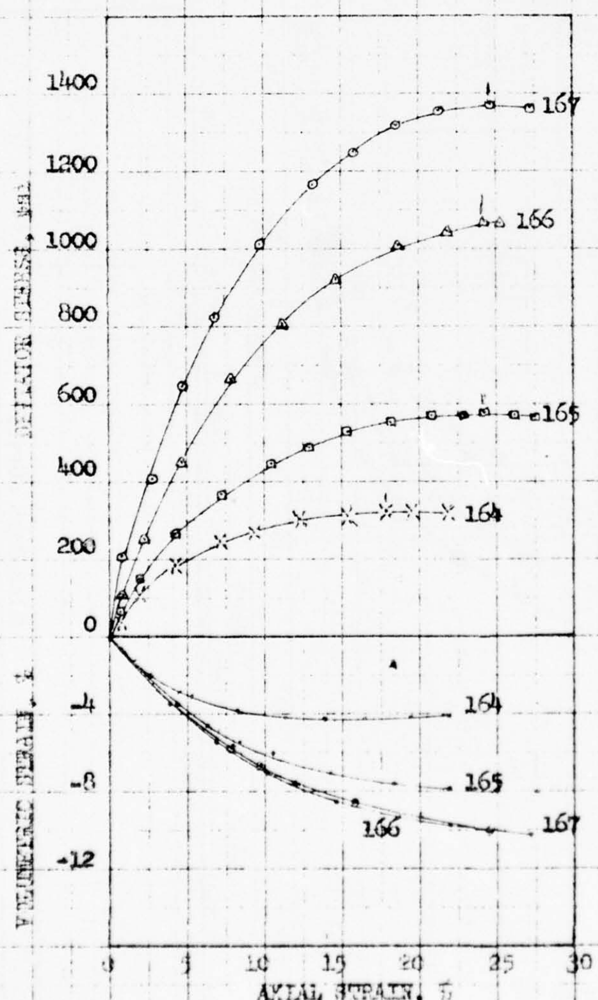
DATE

GRADATION CURVES

ENG FORM 1 MAY 63 2087 REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE (TRANSLUCENT) SPDL

U.S. GOVERNMENT PRINTING OFFICE 1963 OF—709-128





Test No.	σ_3 psi	Dry Density, pcf Initial	Dry Density, pcf Test
164	60	117.1	121.7
165	125	117.2	123.9
166	300	116.9	128.6
167	400	117.2	131.2

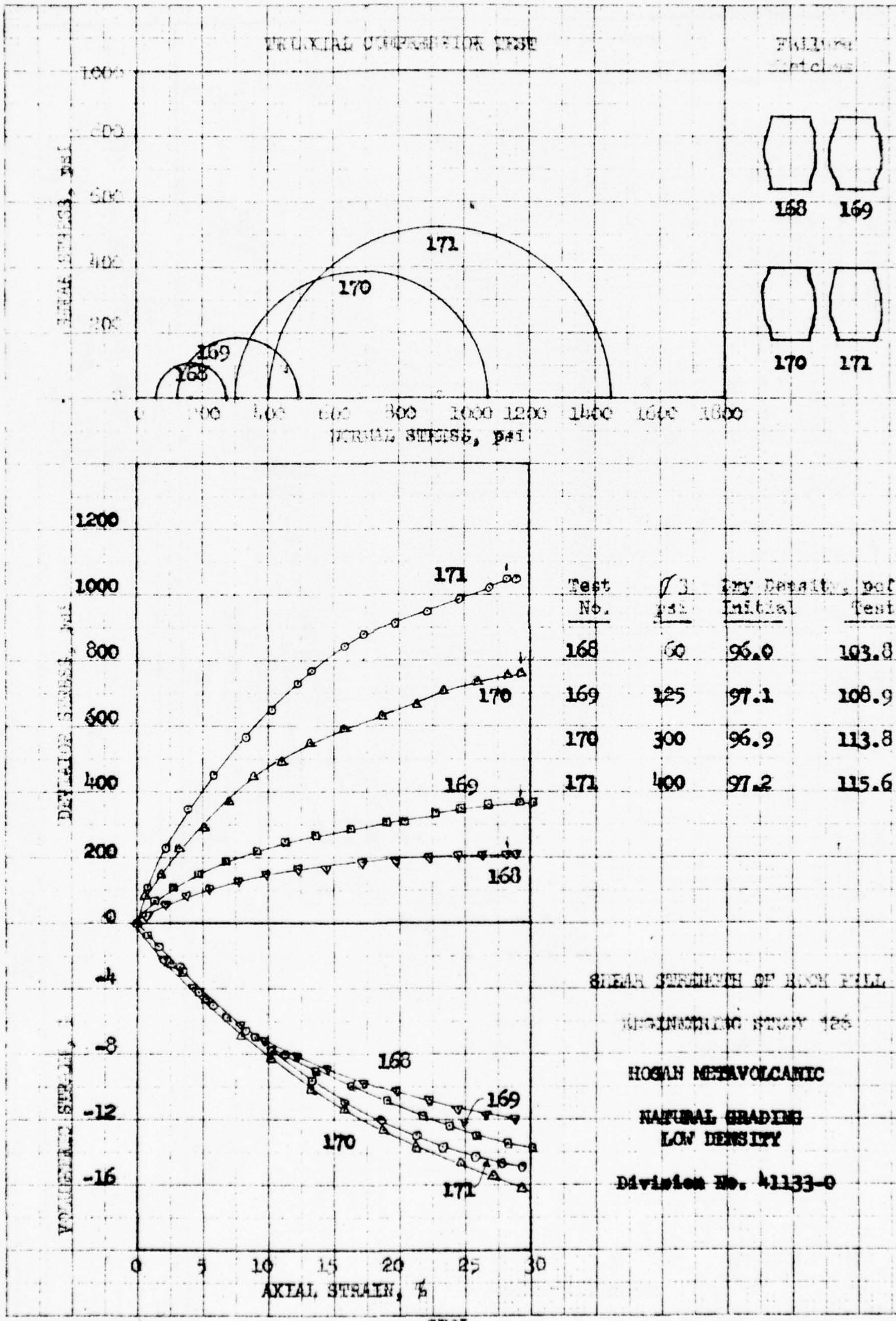
SHEAR STRENGTH OF ROCK FILL

ENGINEERING STUDY [illegible]

HOGAN METAVOLCANIC

NATURAL GRADING
HIGH DENSITY

Division No. 41133-0



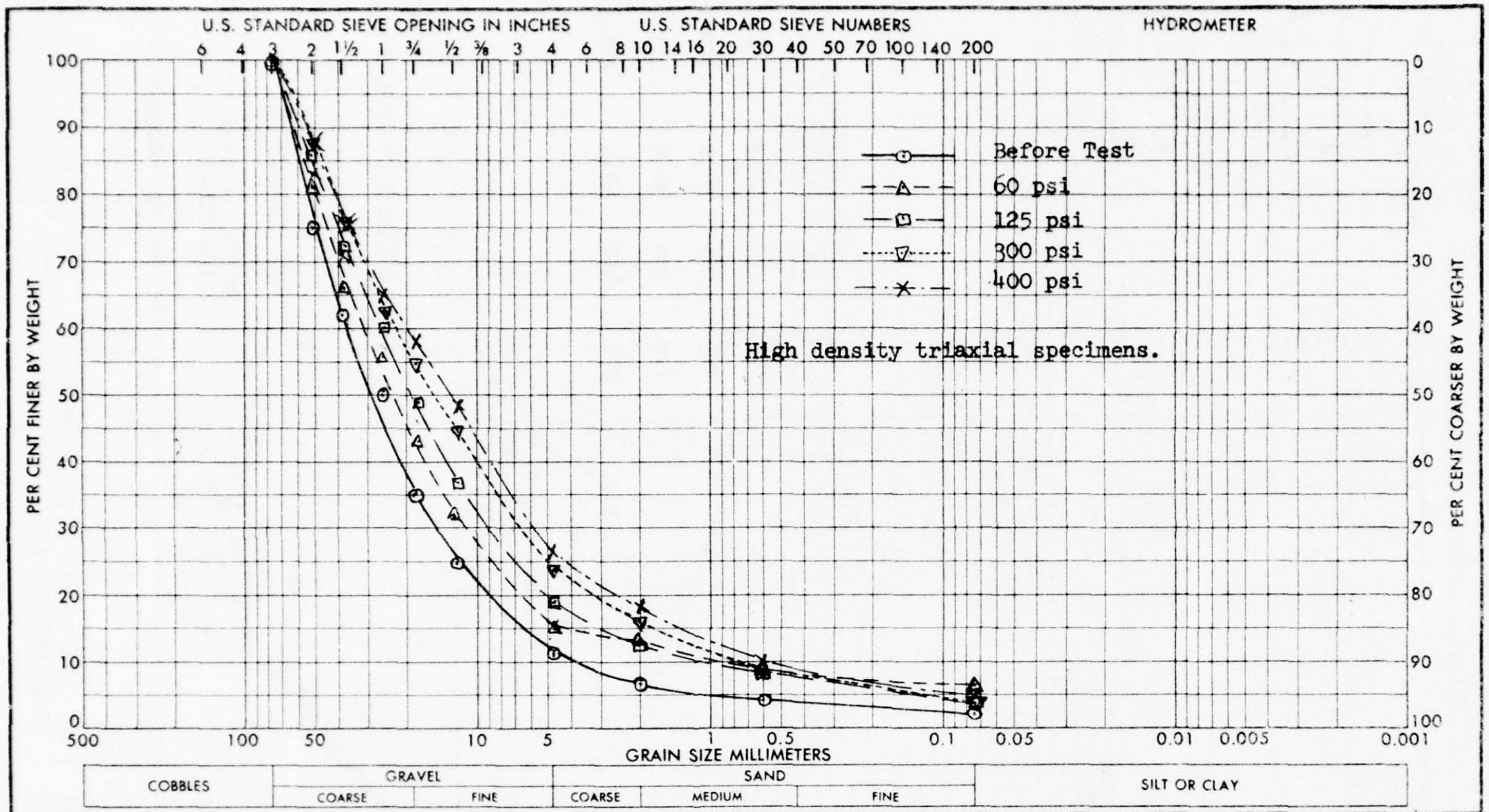
Test No.	σ_3 psi	Dry Density, pcf Initial	Test
168	60	96.0	103.8
169	125	97.1	108.9
170	300	96.9	113.8
171	400	97.2	115.6

SHEAR STRENGTH OF ROCK FILL

HOGAN METAVOLCANIC

NATURAL GRADING
LOW DENSITY

Division No. 41133-0



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

PROJECT ES 526

SHEAR STRENGTH OF ROCK FILL

AREA New Hogan Metavolcanic

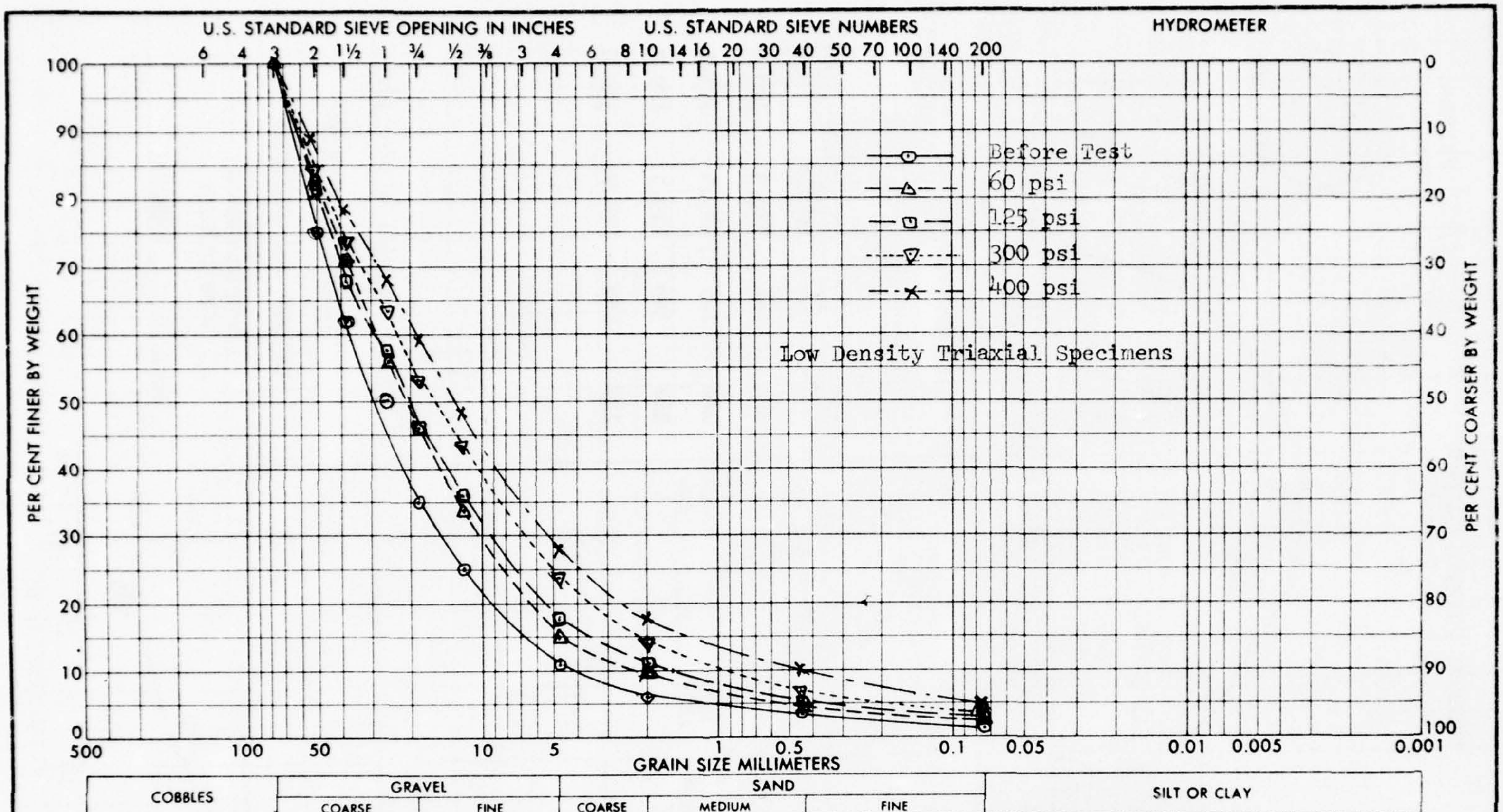
BORING NO Natural Gradation

DATE

GRADATION CURVES

ENG FORM 2087 1 MAY 63 REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE. (TRANSLUCENT) SPDL

U.S. GOVERNMENT PRINTING OFFICE 1963 OF—706-126



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

PROJECT ES 526

SHEAR STRENGTH OF ROCK FILL

~~AREA~~ New Hogan Metavolcanic

~~BORING NO~~ Natural Grading

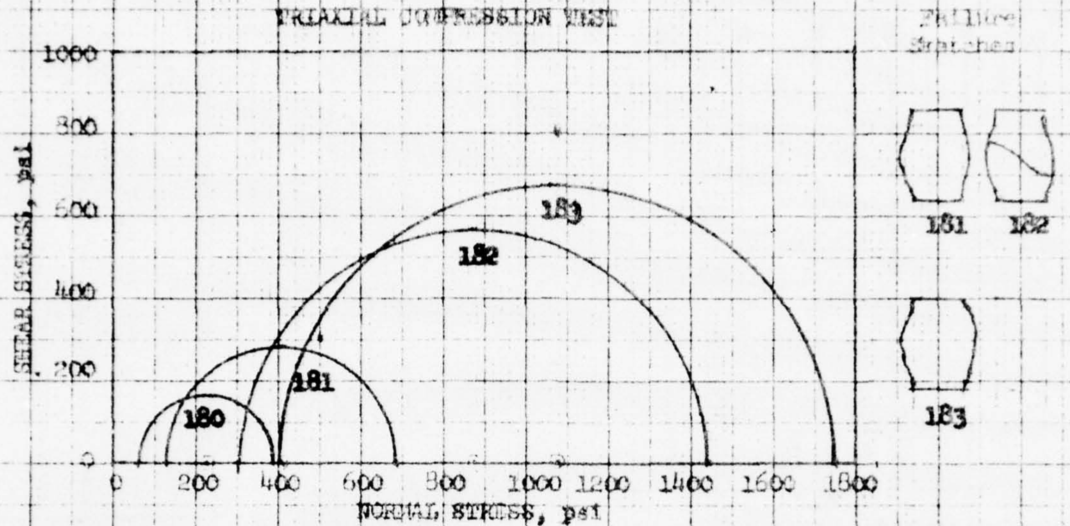
~~DATE~~

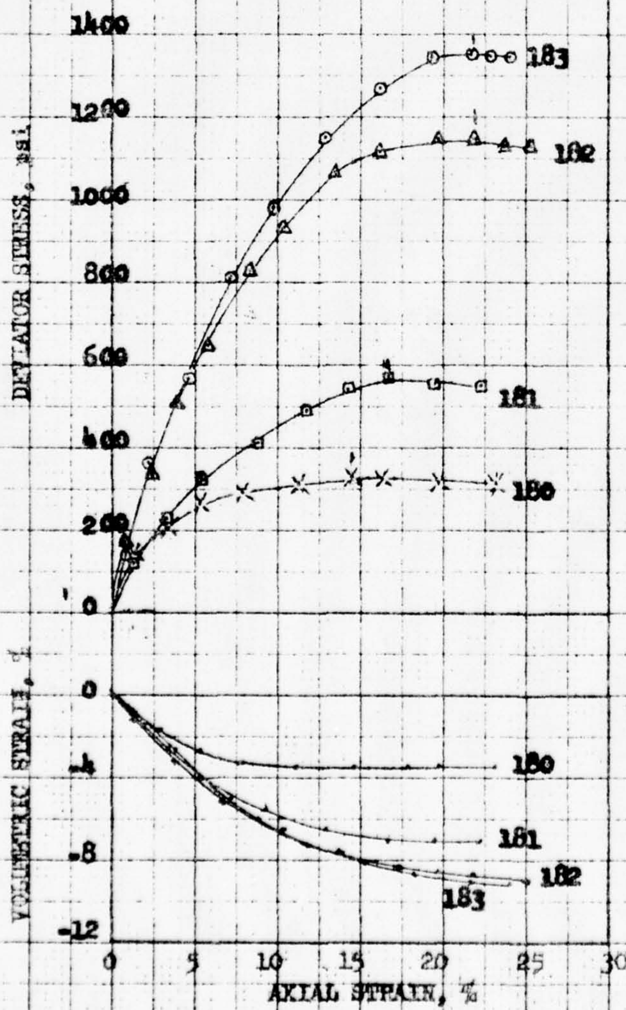
GRADATION CURVES

ENG FORM 2087 1 MAY 63 REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE. (TRANSLUCENT)

SPDL

U.S. GOVERNMENT PRINTING OFFICE 1963 OF—709-126





Test No.	σ_3 psi	Dry Density, pcf Initial	Test
180	60	119.3	123.6
181	125	119.5	124.1
182	300	119.5	129.2
183	400	118.7	130.8

SHEAR STRENGTH OF ROCK FILL

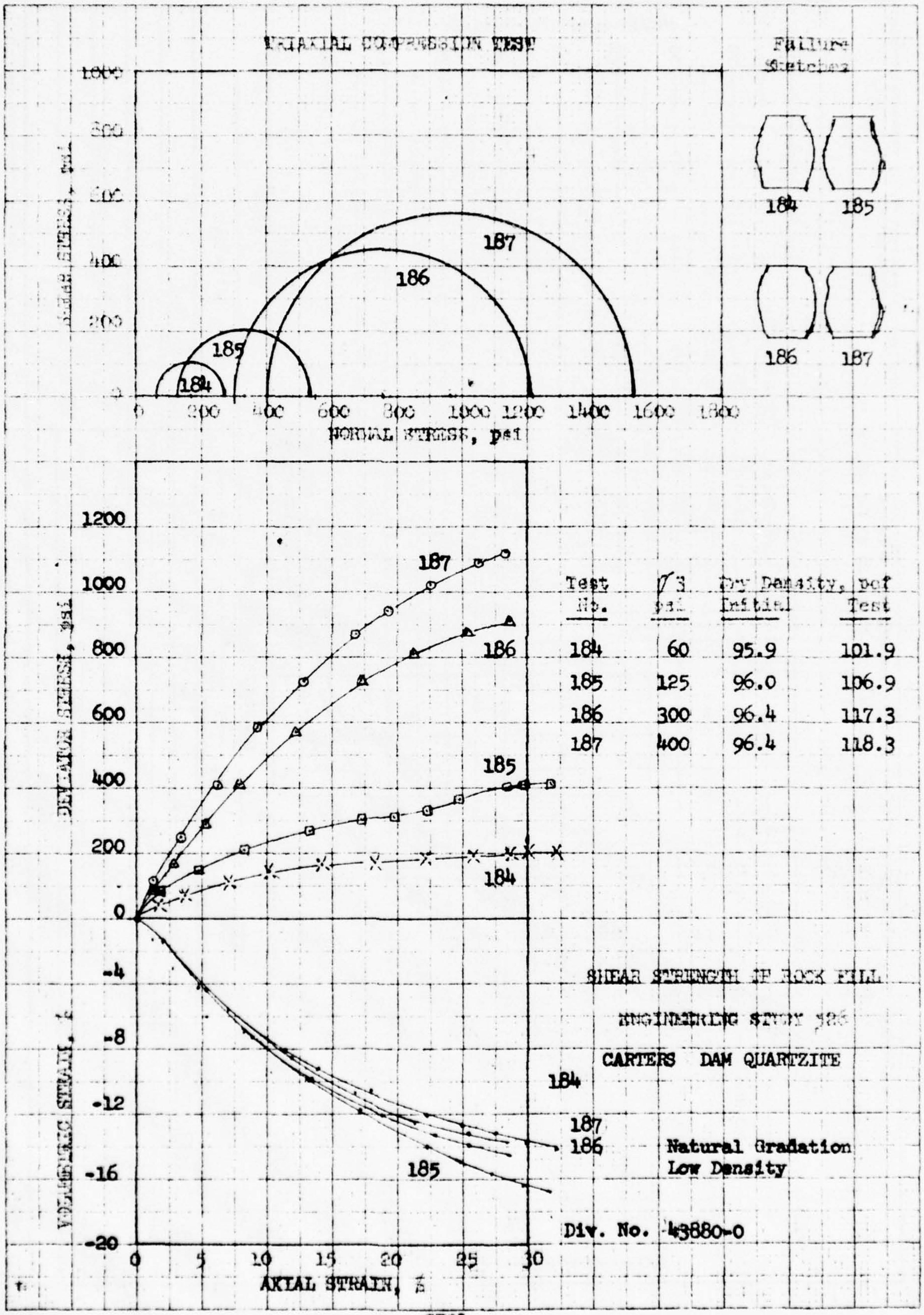
ENGINEERING STUDY 526

CARTERS DAM QUARTZITE

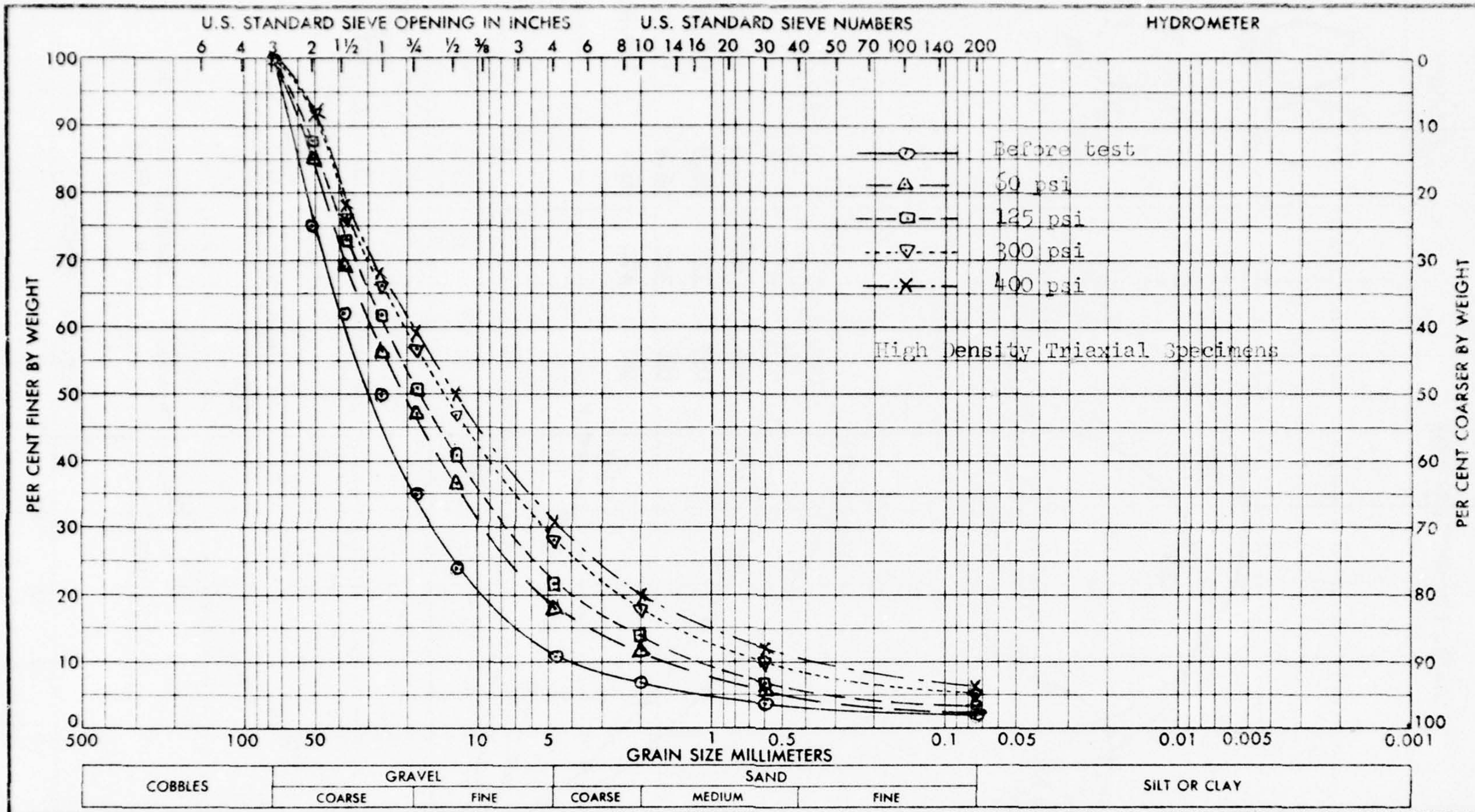
NATURAL GRADING
HIGH DENSITY

Division No. 4388-C

SPDL


TRIAXIAL COMPRESSION TEST
Failure Sketches
184
185
186
187
SHEAR STRESS, psi
NORMAL STRESS, psi
DEVIATOR STRESS, psi
Test No.
σ3 psi
Dry Density, pcf Initial
Test
184 60 95.9 101.9
185 125 96.0 106.9
186 300 96.4 117.3
187 400 96.4 118.3
VOLUMETRIC STRAIN, %
AXIAL STRAIN, %
SHEAR STRENGTH OF ROCK FILL
ENGINEERING STUDY 536
CARTERS DAM QUARTZITE
Natural Gradation
Low Density
Div. No. 43880-0

SPDL



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

PROJECT ES 526

SHEAR STRENGTH OF ROCK FILL

AREA Carters Dam Quartzite

BORING NO. Natural Grading

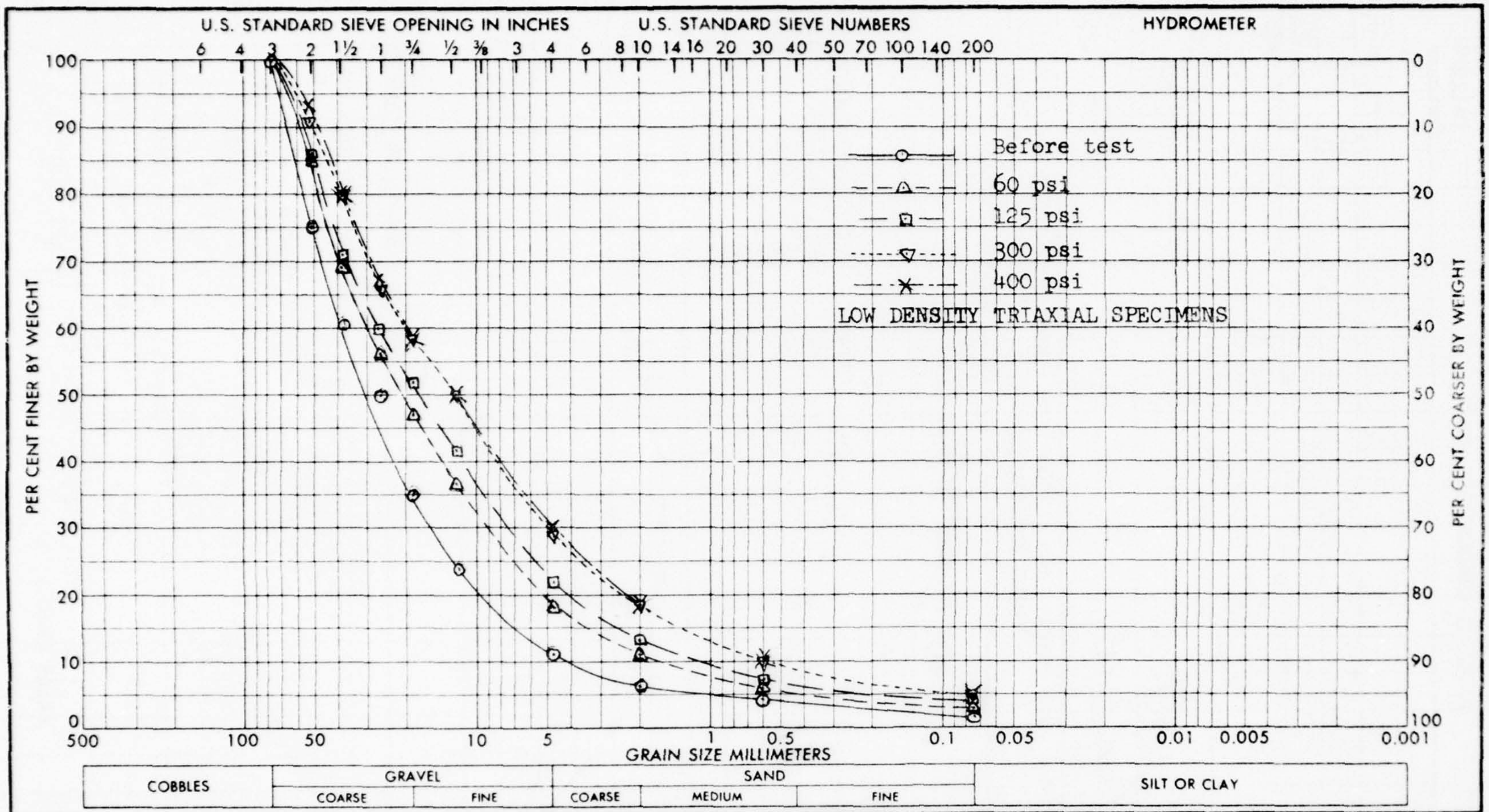
DATE

GRADATION CURVES

ENG FORM 1 MAY 63 2087 REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE. (TRANSLUCENT)

U.S. GOVERNMENT PRINTING OFFICE 1963 OF—709-126

SPDL



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

PROJECT ES 526

SHEAR STRENGTH OF ROCK FILL

AREA Carters Dam Quartzite

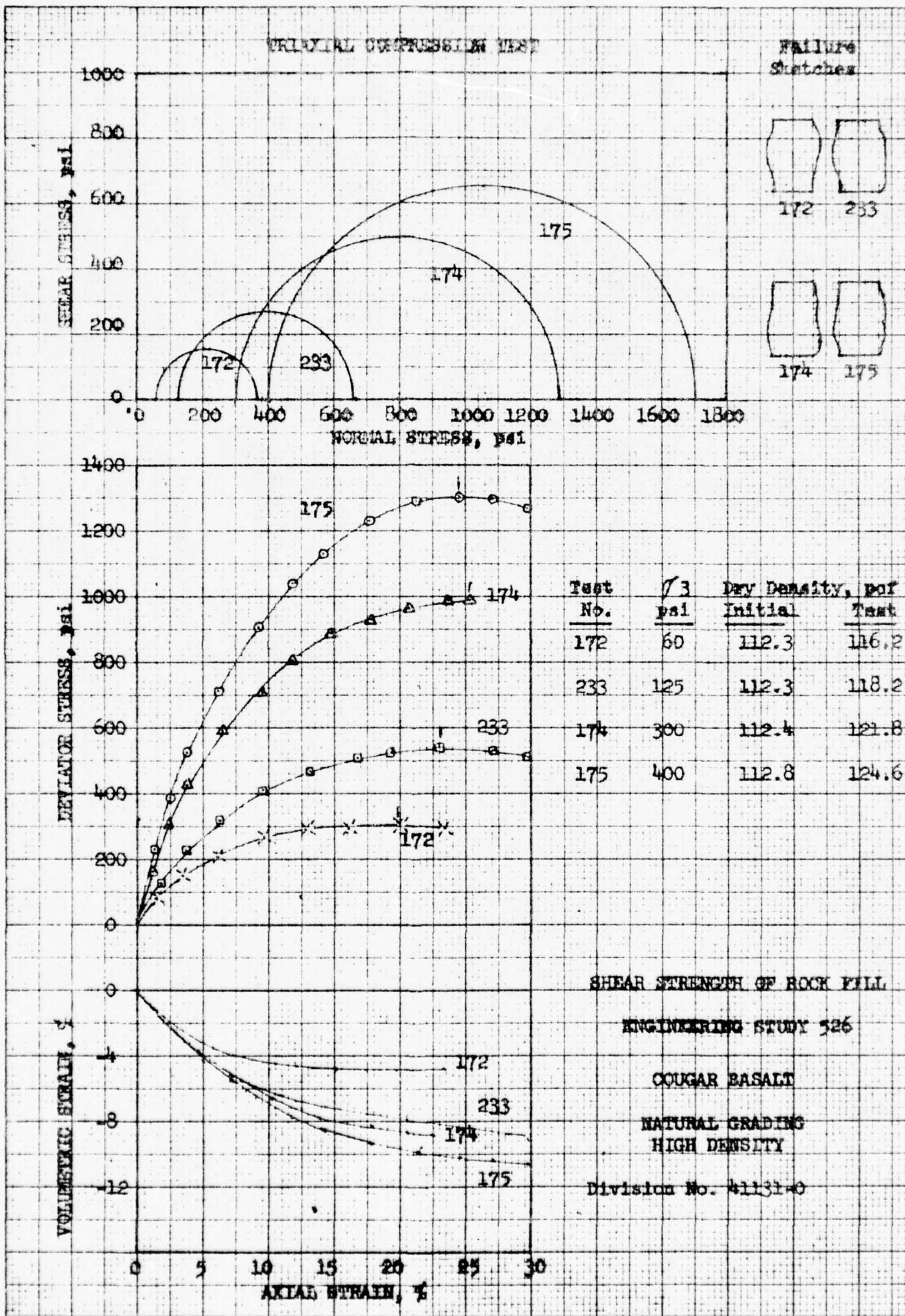
BORING NO. Natural Grading

DATE

GRADATION CURVES

ENG FORM 1 MAY 63 2087 REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE. (TRANSLUCENT) SPDL

U.S. GOVERNMENT PRINTING OFFICE 1963 OF—709-126



Test No.	σ_3 psi	Dry Density, pcf Initial	Test
172	60	112.3	116.2
233	125	112.3	118.2
174	300	112.4	121.8
175	400	112.8	124.6

SHEAR STRENGTH OF ROCK FILL

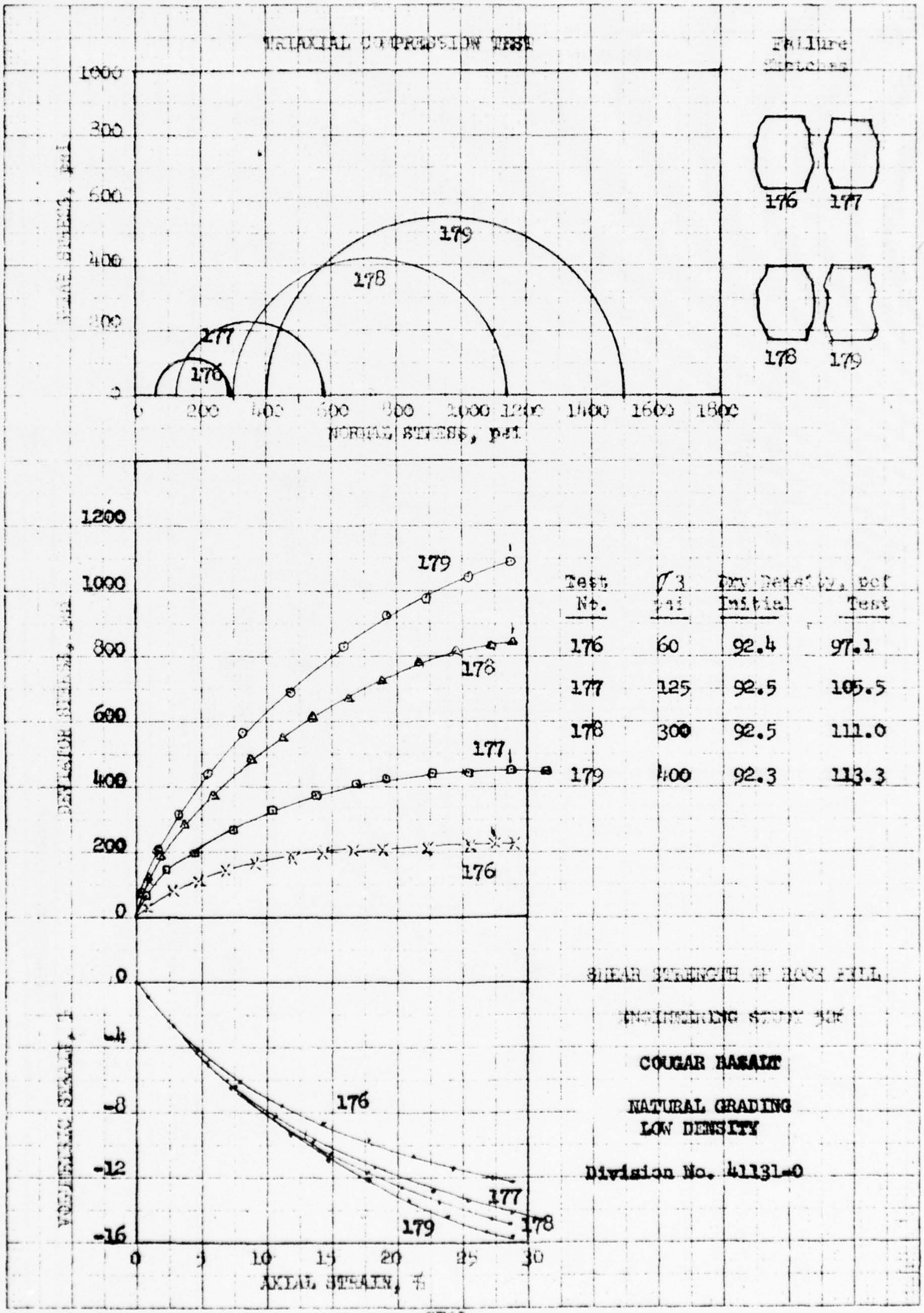
ENGINEERING STUDY 526

COUGAR BASALT

NATURAL GRADING
HIGH DENSITY

Division No. 41131-0

SPDL



Test No.	σ_3 psi	Dry Density, pcf Initial	Dry Density, pcf Test
176	60	92.4	97.1
177	125	92.5	105.5
178	300	92.5	111.0
179	400	92.3	113.3

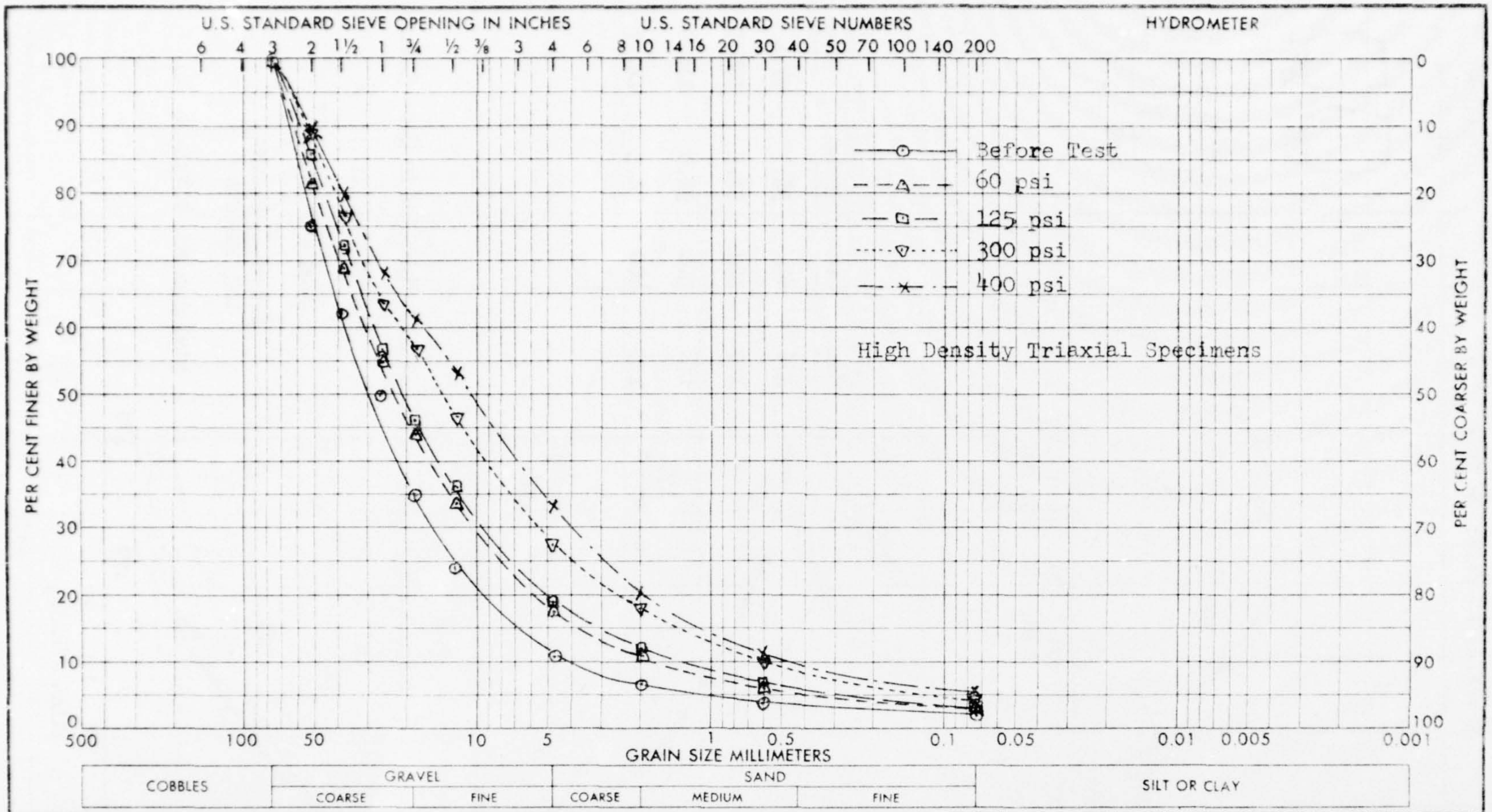
SHEAR STRENGTH OF ROCK FILL

ENGINEERING STUDY 568

COUGAR BASALT

NATURAL GRADING
LOW DENSITY

Division No. 41131-0



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

PROJECT ES 526

SHEAR STRENGTH OF ROCK FILL

~~AREA~~ COUGAR BASALT

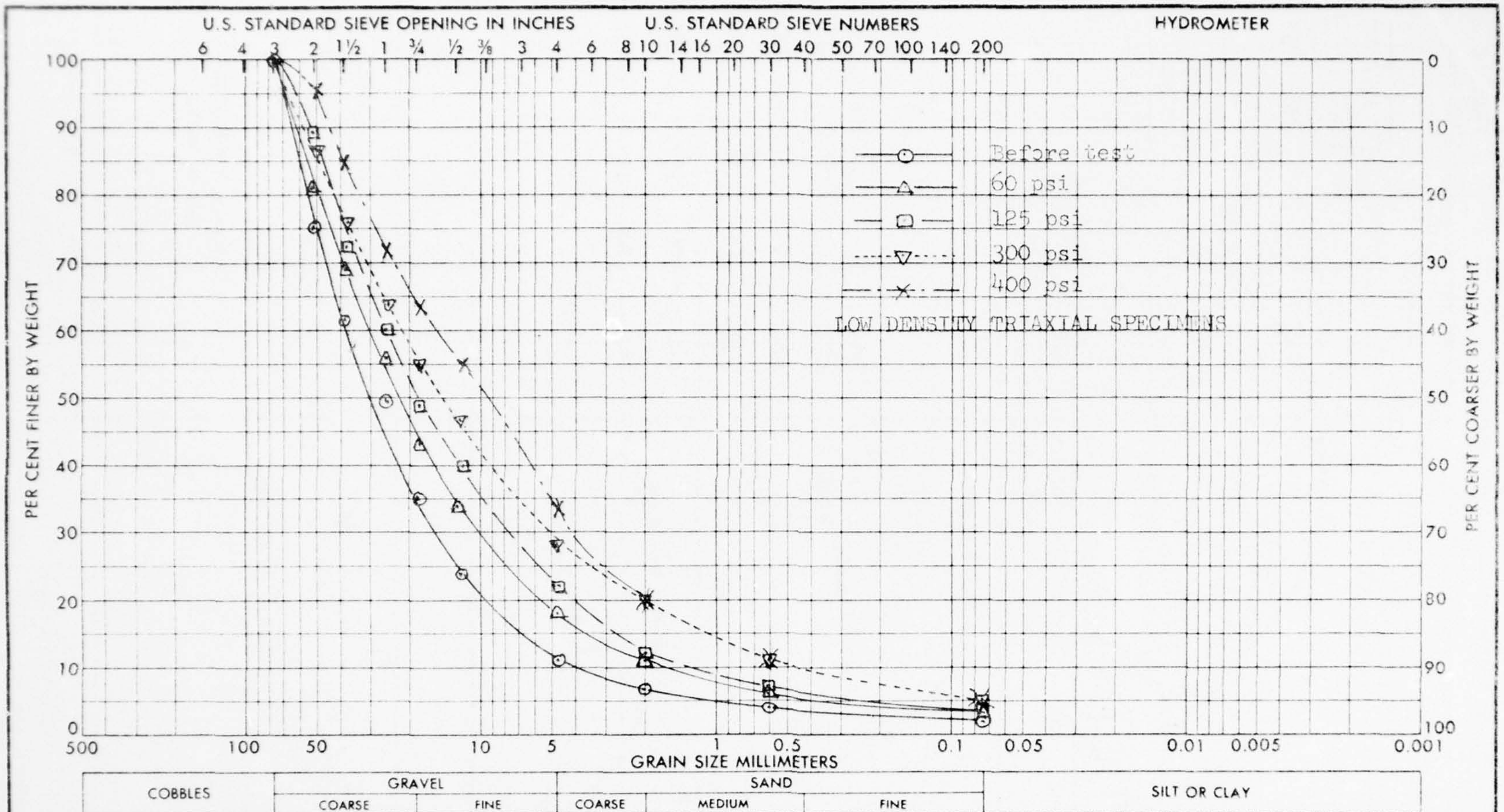
~~BORING NO~~ NATURAL GRADING

~~DATE~~

GRADATION CURVES

ENG FORM 2087 1 MAY 63 REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE. (TRANSLUCENT) SPDL

U.S. GOVERNMENT PRINTING OFFICE 1963 OF—709-126



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

PROJECT ES 526

SHEAR STRENGTH OF ROCK FILL

~~AREA~~ Cougar Basalt

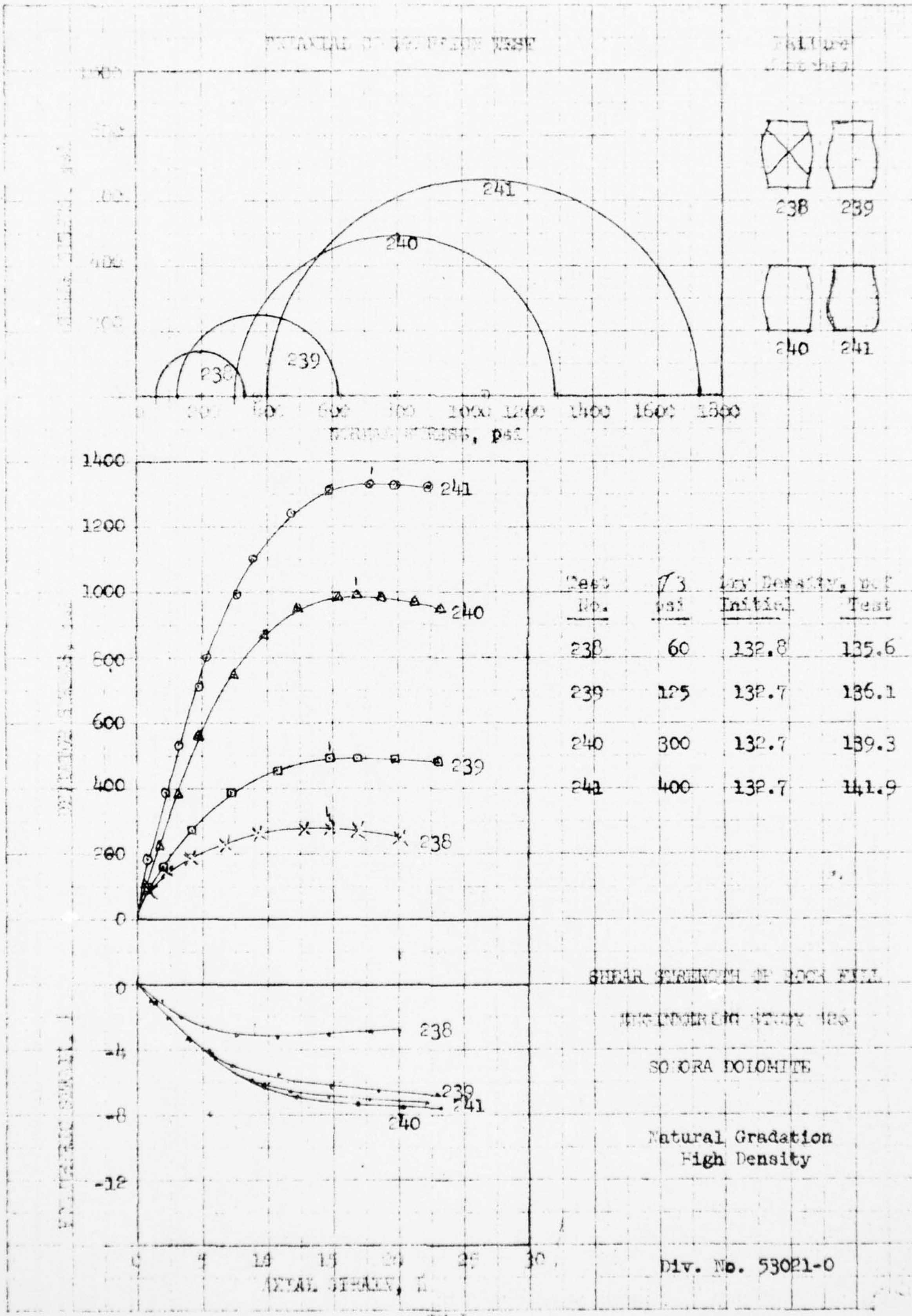
~~BORING NO~~ Natural Grading

~~DATE~~

GRADATION CURVES

ENG FORM 2087 REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE. (TRANSLUCENT) SPDL
1 MAY 63

U.S. GOVERNMENT PRINTING OFFICE 1963 OF—709-126



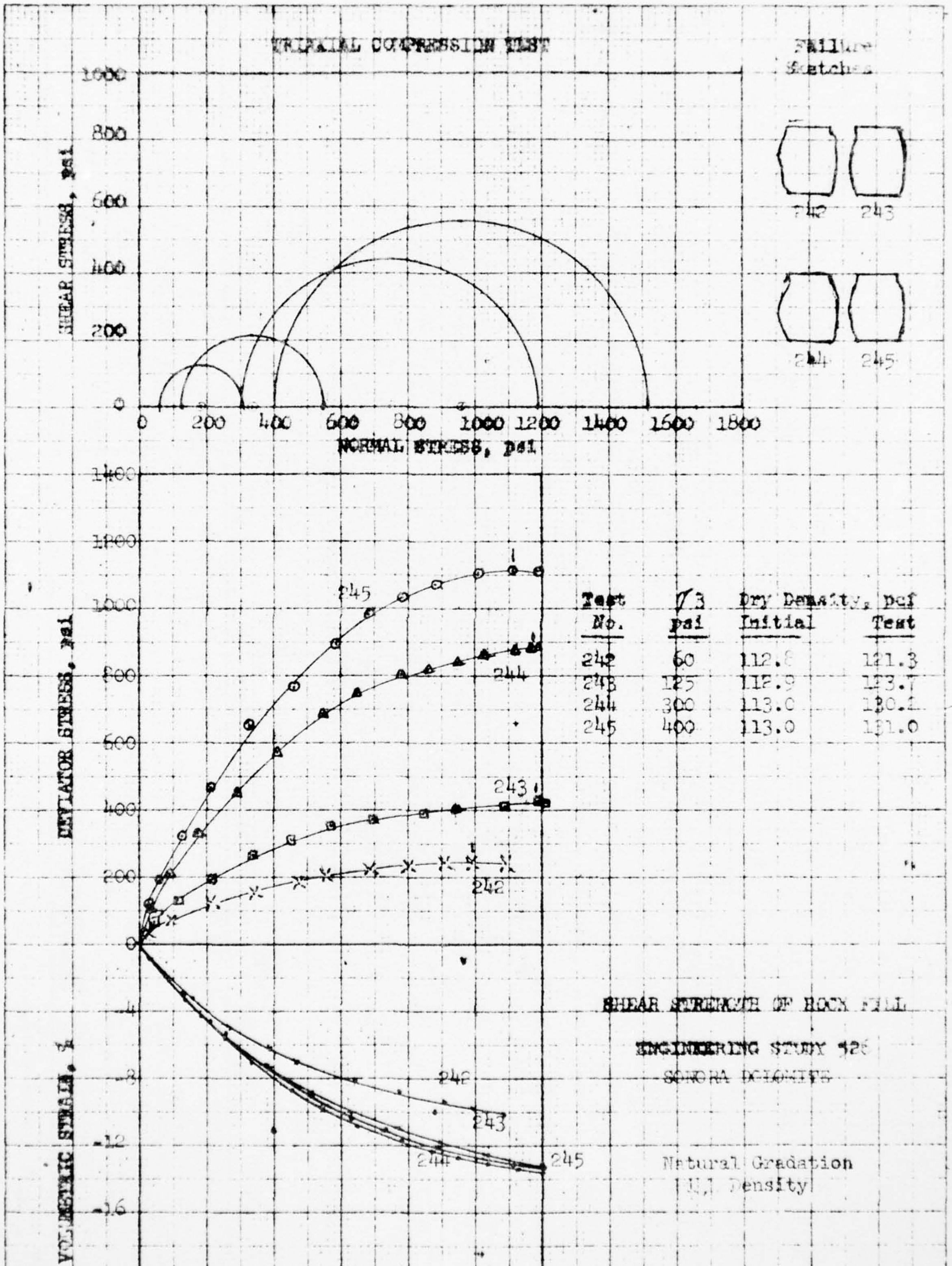
Test No.	σ_3 psi	Dry Density, pcf Initial	Test
238	60	132.8	135.6
239	125	132.7	136.1
240	300	132.7	139.3
241	400	132.7	141.9

SHEAR STRENGTH OF ROCK FILL

SONORA DOLOMITE

Natural Gradation
High Density

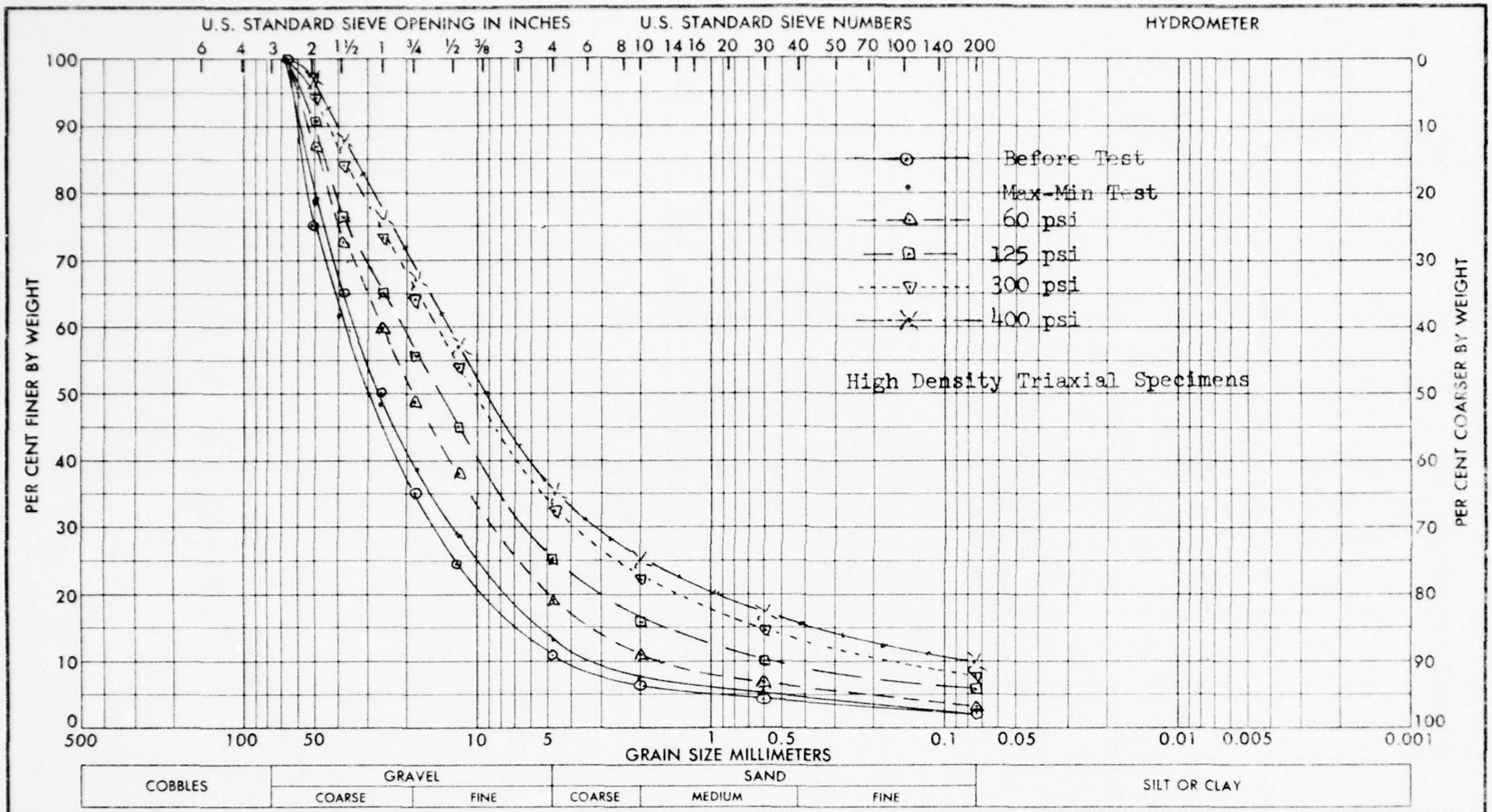
Div. No. 53021-0



Test No.	σ_3 psi	Dry Density, pcf Initial	Test
242	60	112.8	121.3
243	125	112.9	123.7
244	300	113.0	130.2
245	400	113.0	131.0

Div. No. 53021-0

SPDL



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

PROJECT ES 526

SHEAR STRENGTH OF ROCK FILL

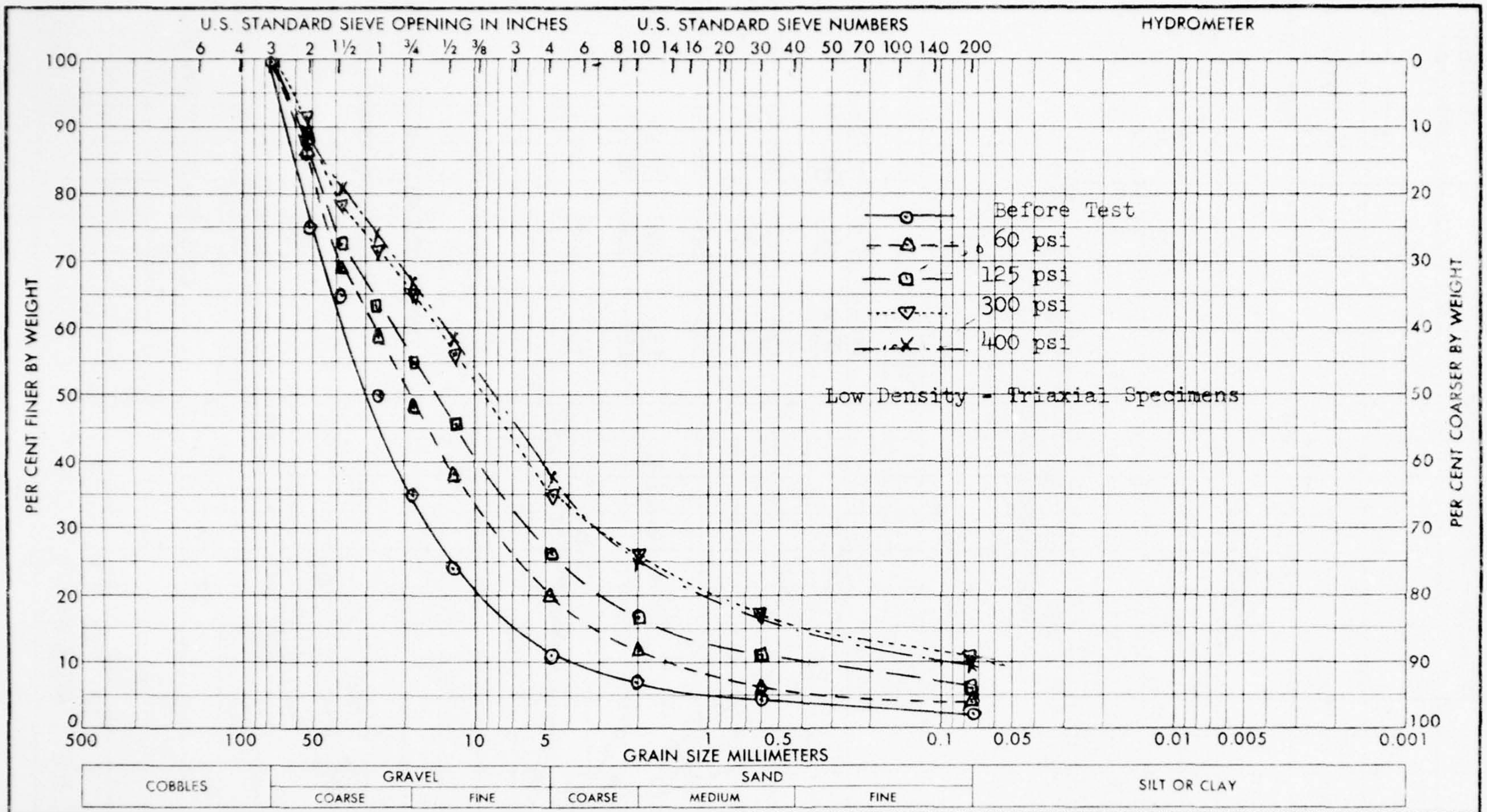
AREA Sonora Dolomite

BORING NO. Natural Gradation

DATE

GRADATION CURVES

ENG FORM 1 MAY 63 **2087** REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE. *(TRANSLUCENT)*



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

PROJECT ES 526

SHEAR STRENGTH OF ROCK FILL

AREA Sonora Dolomite

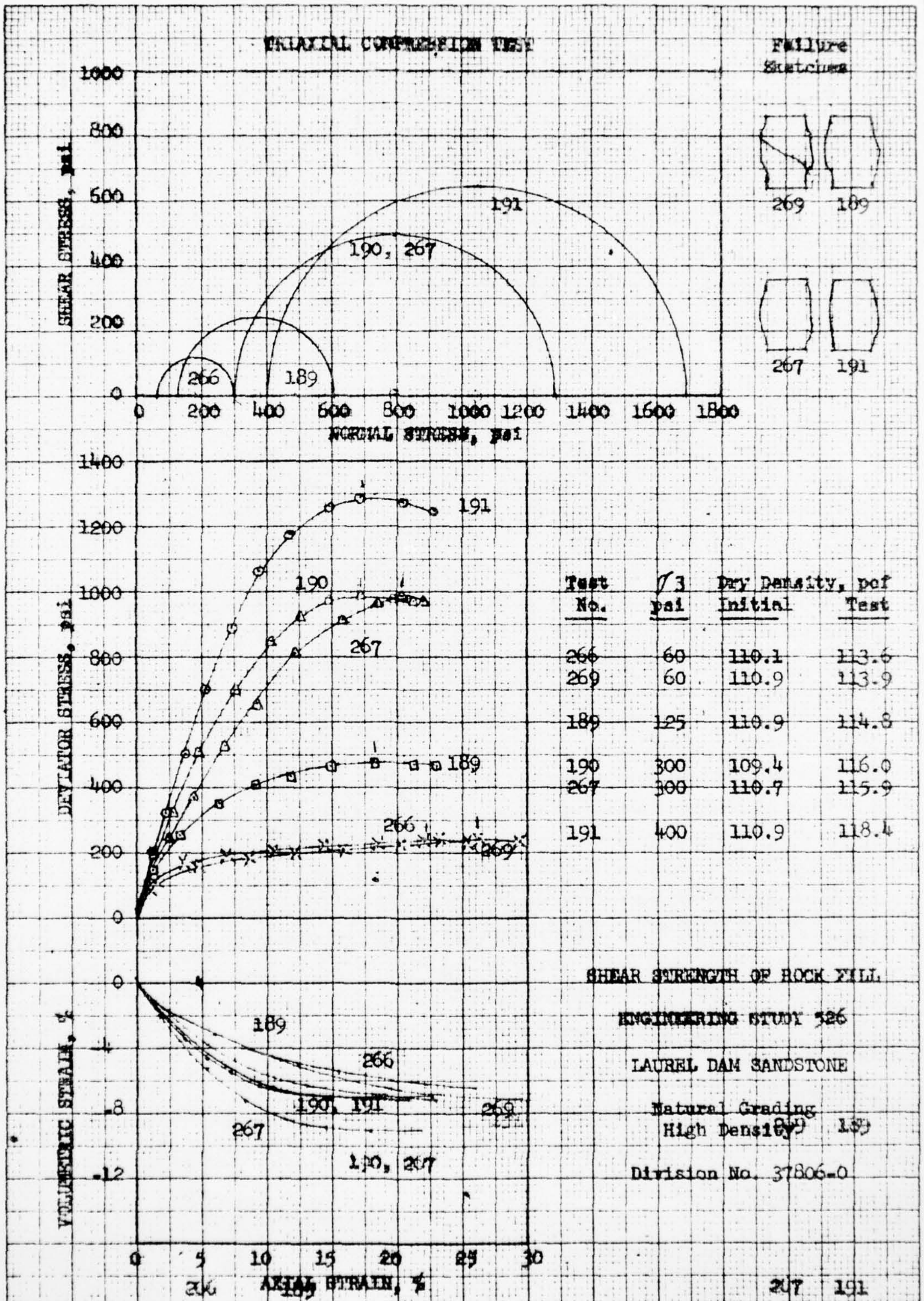
BORING NO Natural Gradation

DATE

GRADATION CURVES

ENG FORM 2087
1 MAY 63

REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE. (TRANSLUCENT)



Test No.	σ_3 psi	Dry Density, pcf Initial	Test
266	60	110.1	113.6
269	60	110.9	113.9
189	125	110.9	114.8
190	300	109.4	116.0
267	300	110.7	115.9
191	400	110.9	118.4

SHEAR STRENGTH OF ROCK FILL

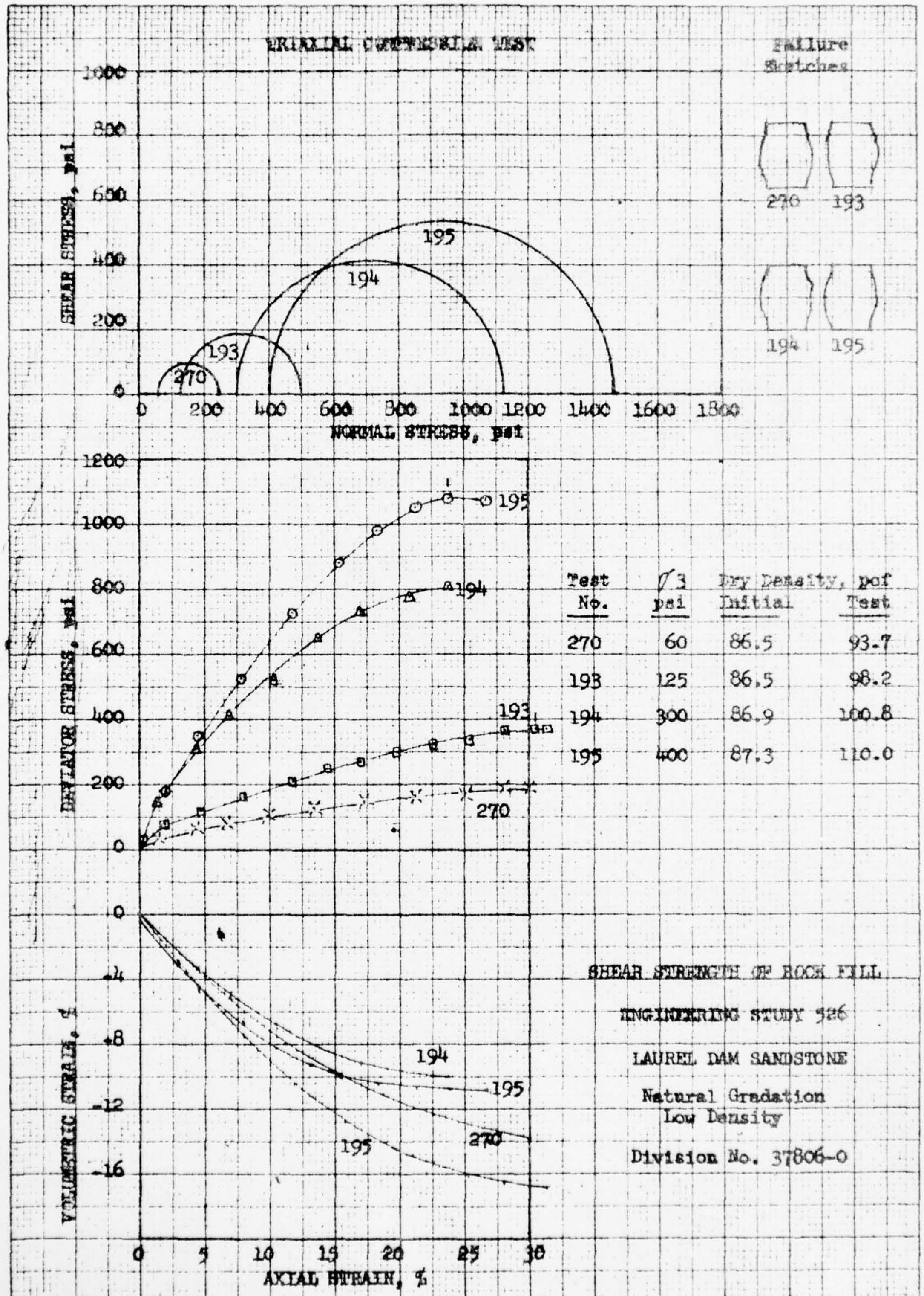
ENGINEERING STUDY 526

LAUREL DAM SANDSTONE

Natural Grading
High Density

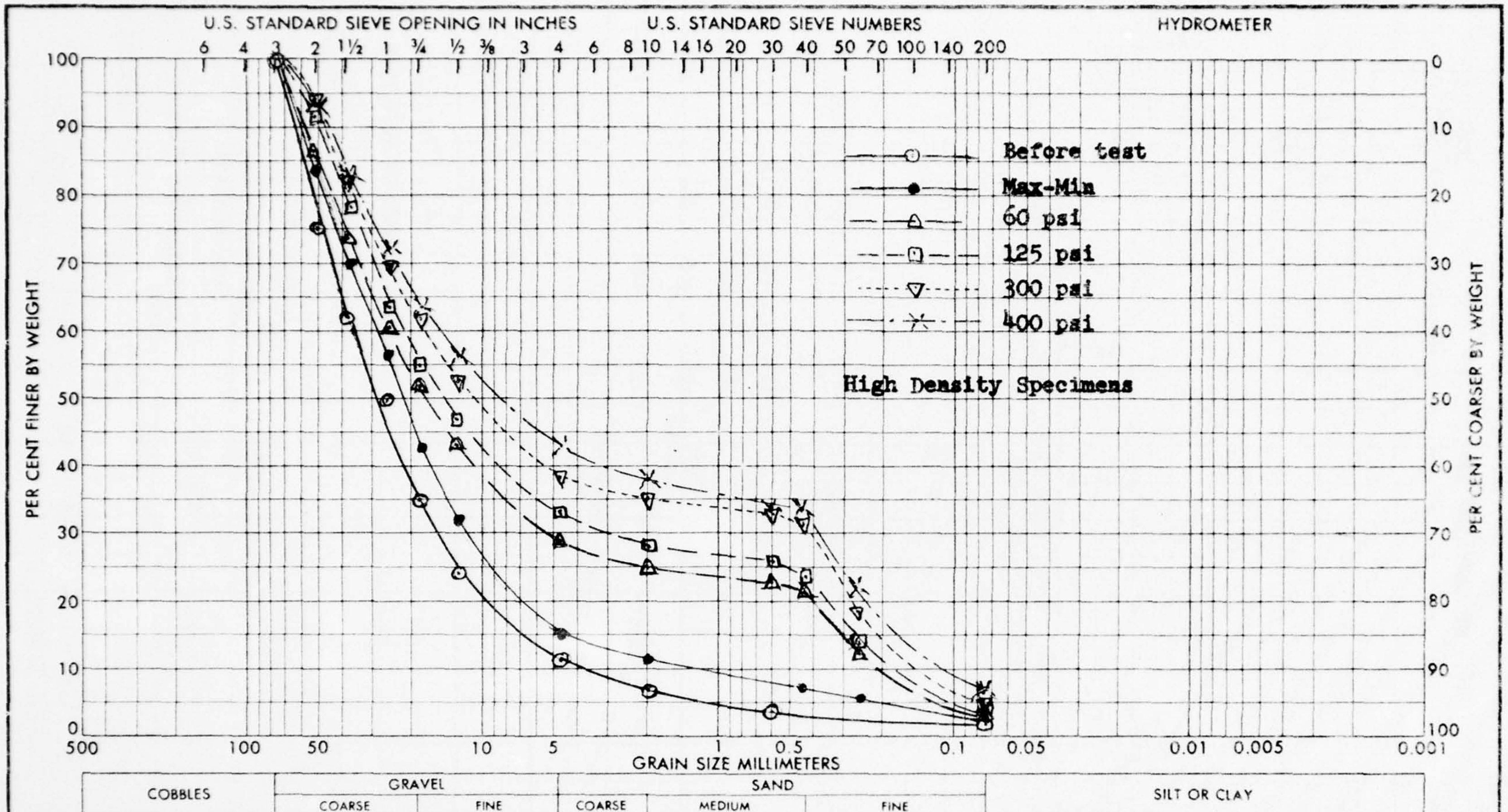
Division No. 37806-0

SPDL



TRIAXIAL COMPRESSION TEST
Failure Sketches
270 193
194 195
SHEAR STRESS, psi
NORMAL STRESS, psi
DEVIATOR STRESS, psi
VOLUMETRIC STRAIN, %
AXIAL STRAIN, %
Test No. | σ_3 psi | Dry Density, pcf Initial | Test
270 | 60 | 86.5 | 93.7
193 | 125 | 86.5 | 98.2
194 | 300 | 86.9 | 100.8
195 | 400 | 87.3 | 110.0
SHEAR STRENGTH OF ROCK FILL
ENGINEERING STUDY 526
LAUREL DAM SANDSTONE
Natural Gradation
Low Density
Division No. 37806-0

SPDL



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

PROJECT ES 526

SHEAR STRENGTH OF ROCK FILL

AREA Laurel Dam Sandstone

~~BORING NO.~~ Natural Grading

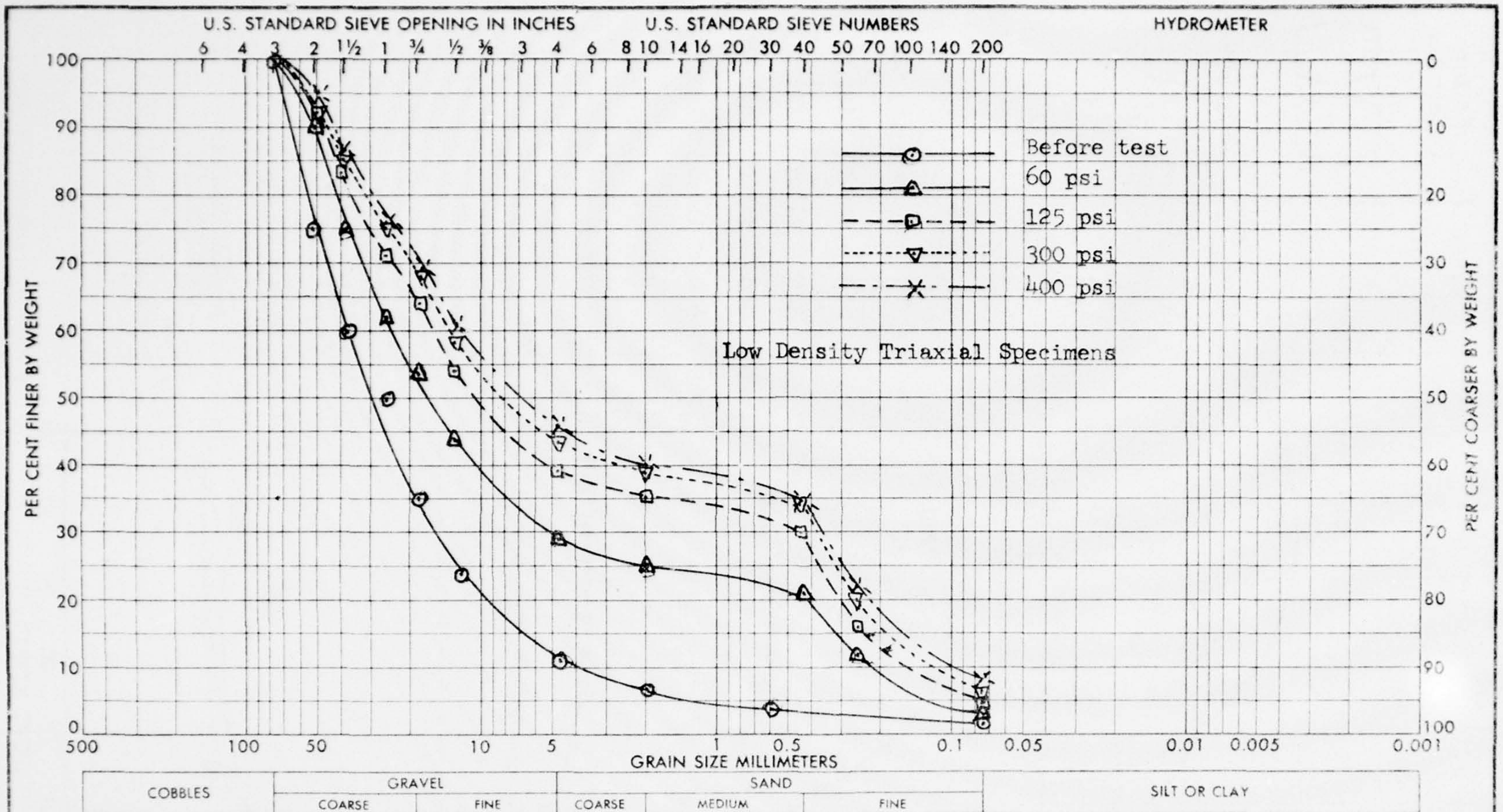
~~DATE~~

GRADATION CURVES

SPDL

ENG FORM 1 MAY 63 2087 REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE. (TRANSLUCENT)

U.S. GOVERNMENT PRINTING OFFICE : 1963 OF—709-126



SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

PROJECT ES 526

SHEAR STRENGTH OF ROCK FILL

AREA Laurel Dam Sandstone

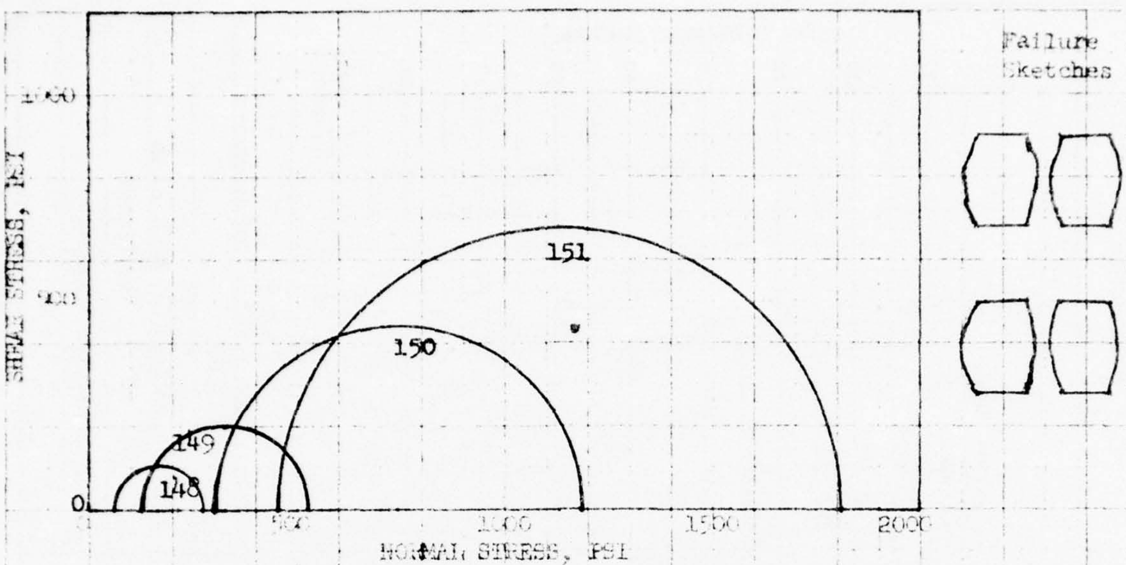
~~BORING NO.~~ Natural Grading

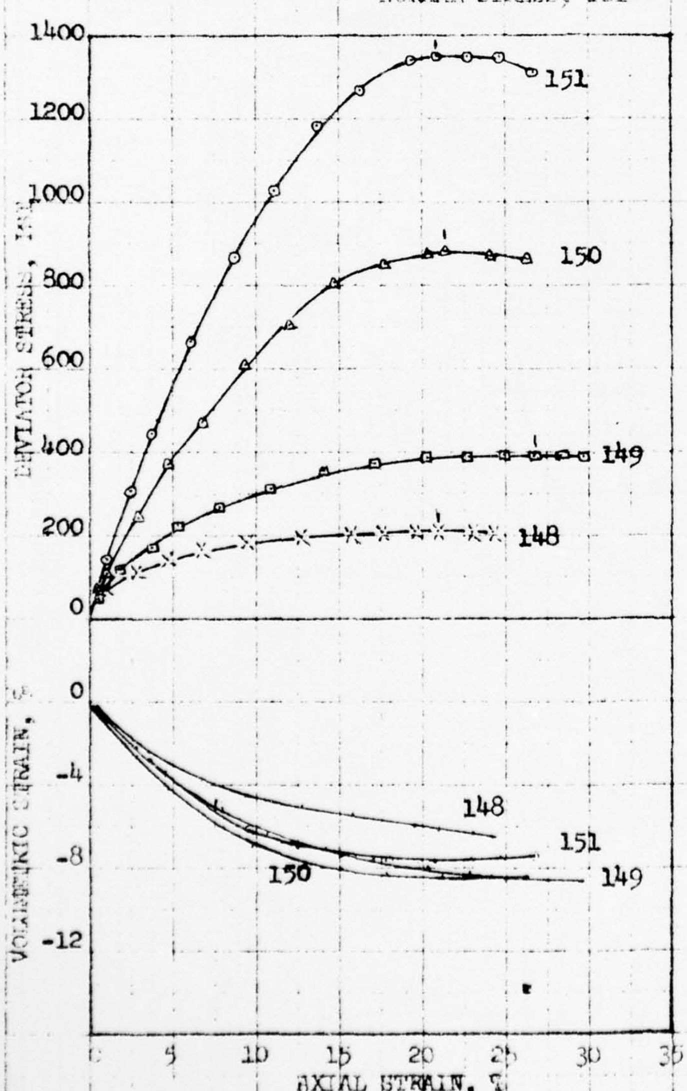
~~DATE~~

GRADATION CURVES

ENG FORM 2087 1 MAY 63 REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE. (TRANSLUCENT)

U.S. GOVERNMENT PRINTING OFFICE 1963 OF—709-126





Test No.	σ_3 psi	Dry Density, pcf Initial	Test
148	60	113.2	121.9
149	125	113.3	123.0
150	300	113.0	127.6
151	450	113.0	130.8

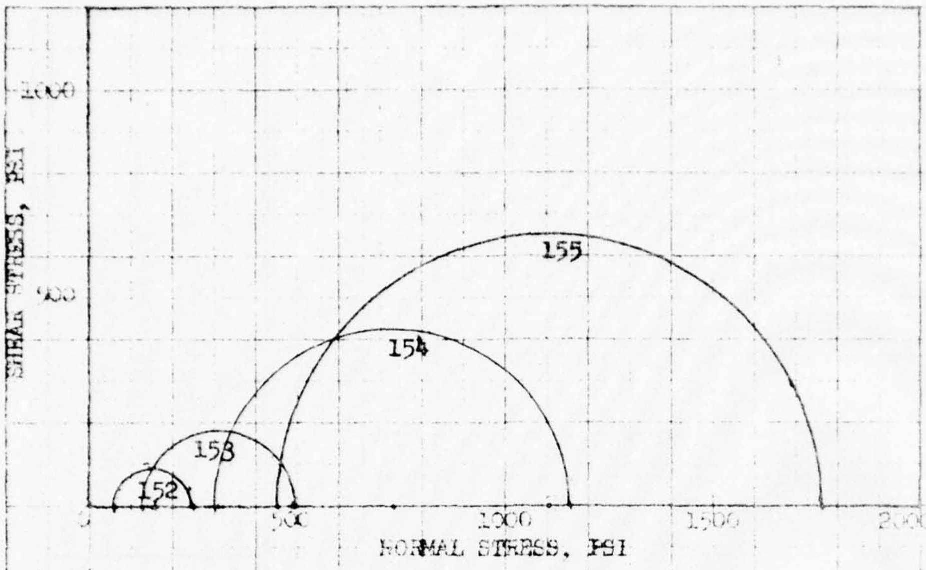
SHEAR STRENGTH OF ROCK FILL
ENGINEERING STUDY 526

BUCHANAN GRANITE

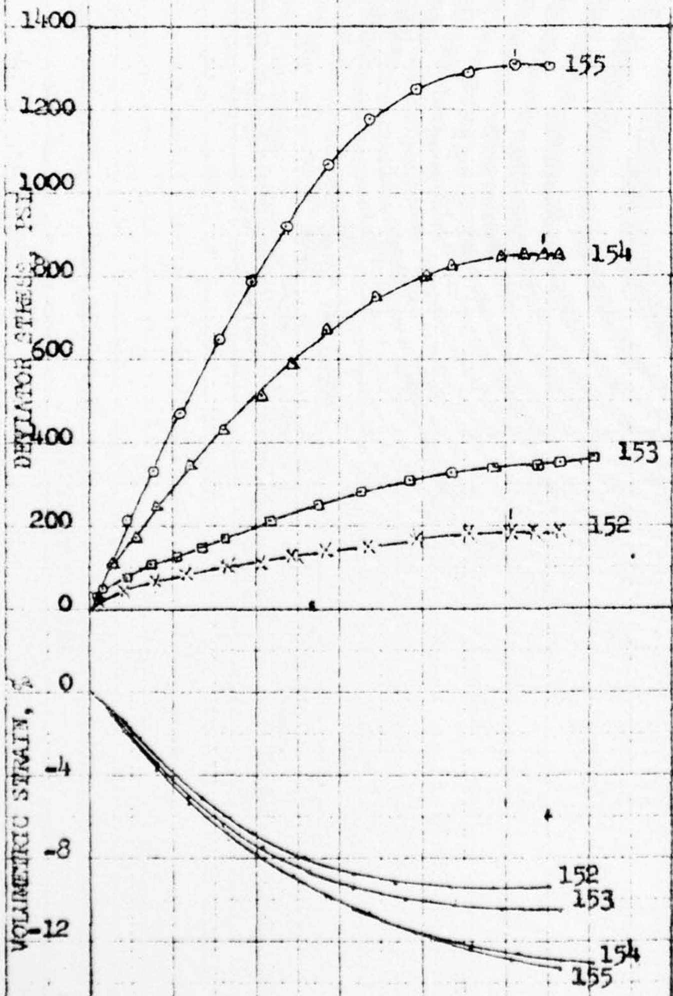
NATURAL GRADING
HIGH DENSITY

Division No. 40969-0

TRIAXIAL COMPRESSION TEST



Failure Sketches



Test No	σ_3 psi	Dry Density, pcf Initial	Test
152	60	98.1	110.6
153	125	97.9	113.5
154	300	98.2	121.8
155	450	98.3	132.9

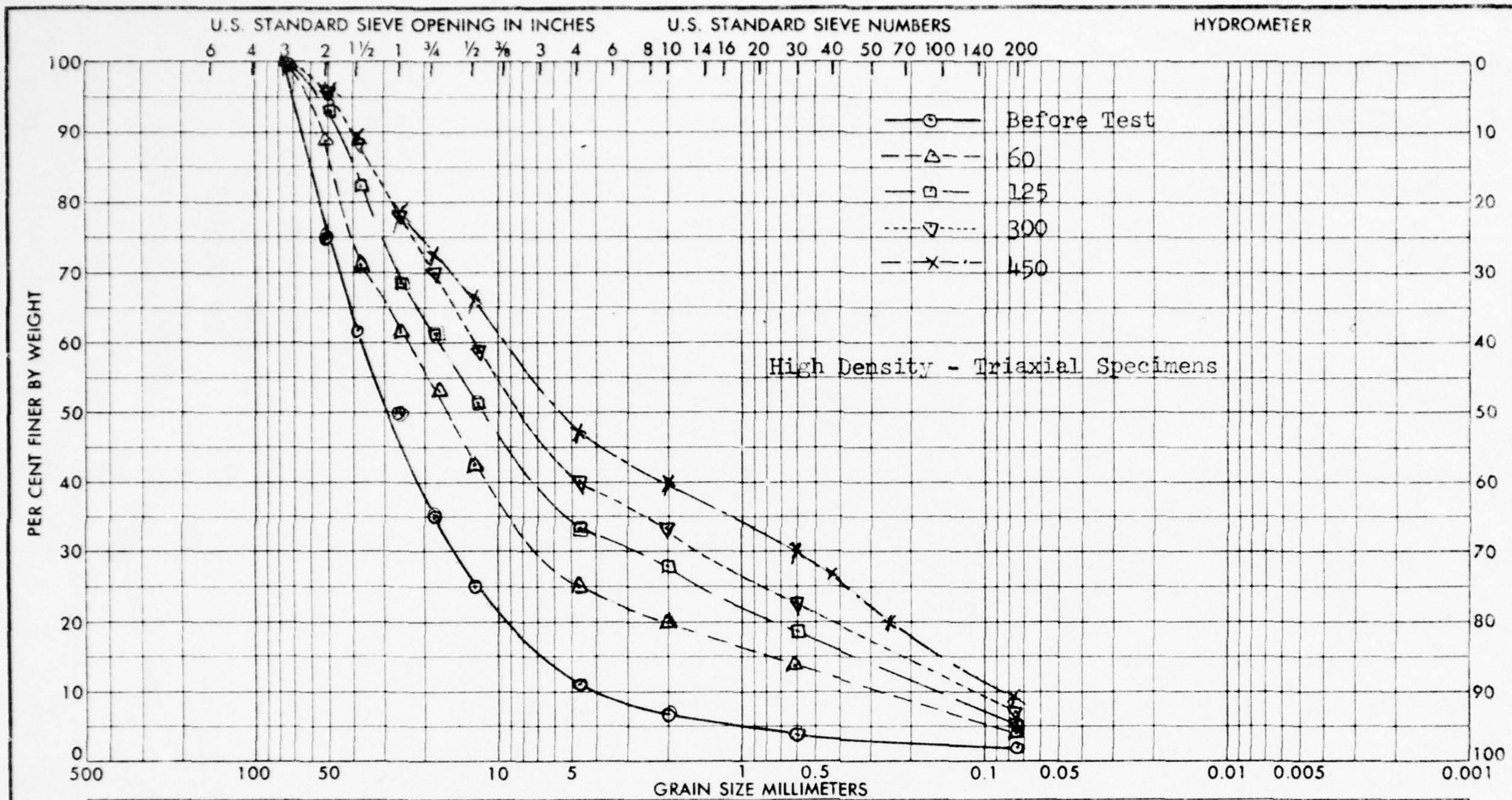
SHEAR STRENGTH OF ROCK FILL
ENGINEERING STUDY 526

BUCHANAN GRANITE

NATURAL GRADING
LOW DENSITY

Division No. 40969-C

TRIAXIAL COMPRESSION TEST



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

GRADATION CURVES

PROJECT ES 526

Shear Strength of Rock Fill

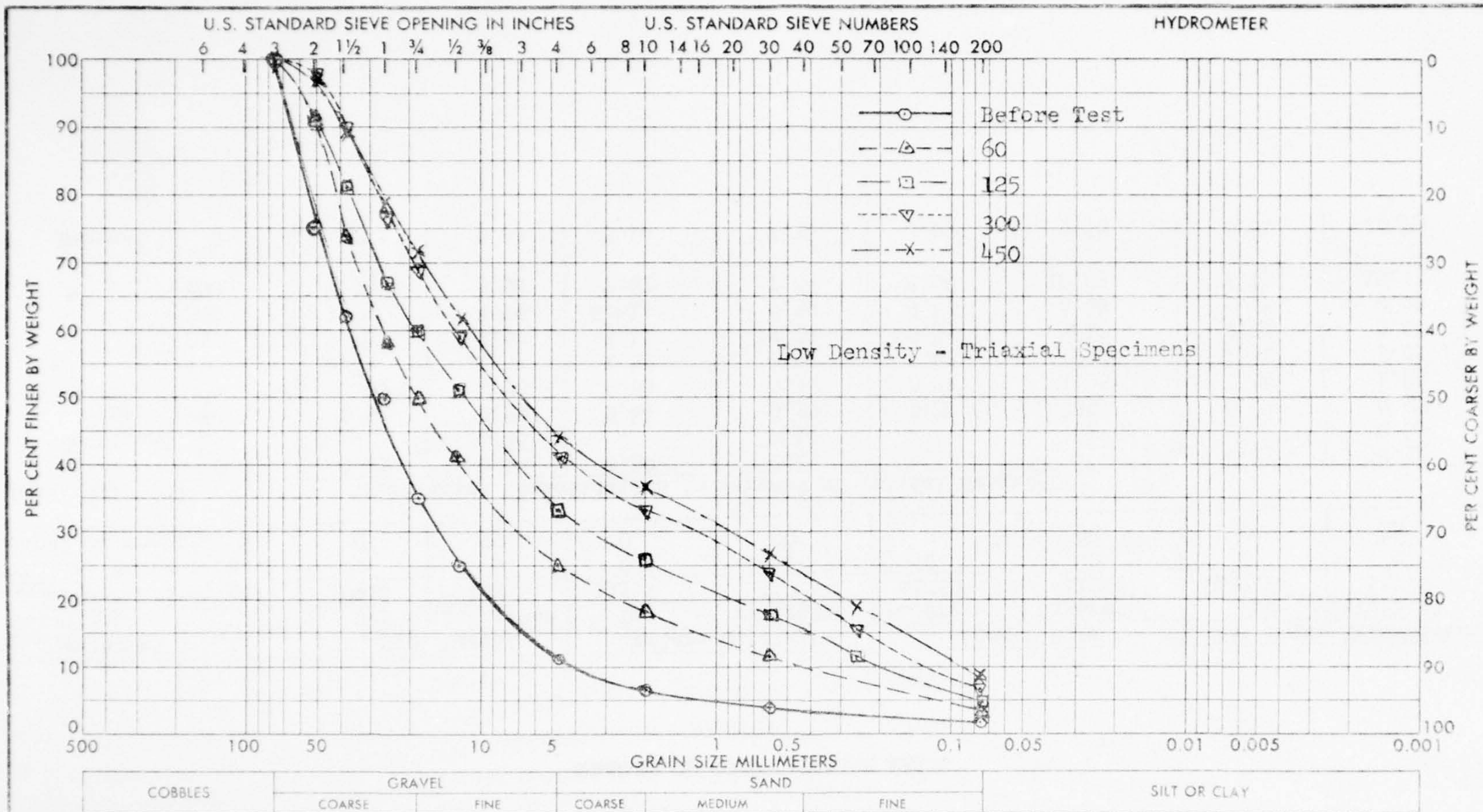
AREA Buchanan Granite

BORING NO Natural Grading

DATE

ENG FORM 2087
1 MAY 63

REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE. *(TRANSLUCENT)* SPDL



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

PROJECT ES 526

Shear Strength of Rock Fill

AREA Buchanan Granite

BORING NO. Natural Grading

DATE

GRADATION CURVES

ENG FORM 2087
1 MAY 63

REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE. (TRANSLUCENT) SPDL

U.S. GOVERNMENT PRINTING OFFICE 1963 OF—709-126

SHEAR STRENGTH OF ROCK FILL

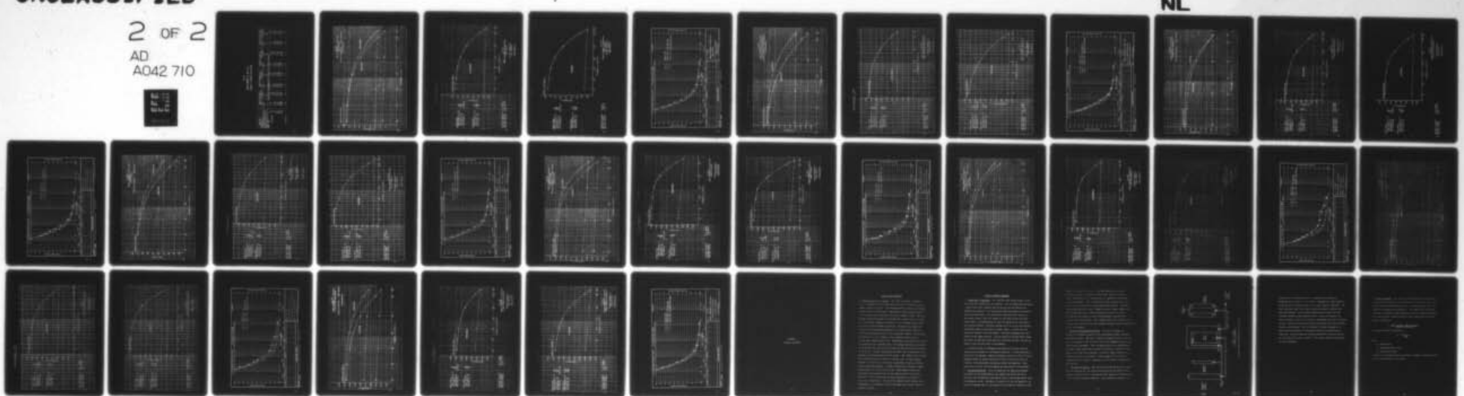
SUMMARY OF CONSOLIDATION TESTS

Material	Napa Basalt		Carters Quartzite		Cougar Basalt		New Hogan Metavolcanic	
Condition	Dry	Saturated	Dry	Saturated	Dry	Saturated	Dry	Saturated
Initial Density, pcf	129.6	129.3	119.7	119.5	112.0	112.0	117.6	117.4
Initial Saturation, %	0	0	0	0	0	0	0	0
Final Saturation, %	0	99	0	90	0	93	0	93
Load, psi	Cumulative Consolidation in Percent of Initial Height							
15	0.25	0.44	0.30	0.13	-	-	0.11	0.52
Submerged 15	-	0.46	-	0.14	-	.31	-	0.65
30	0.36	0.59	0.44	0.20	0.37	.39	0.17	0.92
60	0.55	0.85	0.80	0.38	0.74	1.05	0.54	1.83
120	0.95	1.34	1.52	0.97	1.43	2.08	1.32	3.05
250	1.78	2.50	3.11	2.73	2.99	4.12	2.77	5.28
600	3.64	4.79	6.41	6.39	5.49	8.44	5.74	9.09
800	4.50	5.86	7.67	7.84	6.88	10.03	7.19	10.73
Rebound 0	4.07	5.24	7.16	7.36	6.29	9.58	6.81	10.23

AD-A042 710 CORPS OF ENGINEERS SAUSALITO CALIF SOUTH PACIFIC DIV LAB F/G 8/7
SHEAR STRENGTH OF ROCKFILL, PHYSICAL PROPERTIES. ENGINEERING ST--ETC(U)
OCT 75 M W COHEN, D D LESLIE

UNCLASSIFIED NL

2 OF 2
AD
A042 710



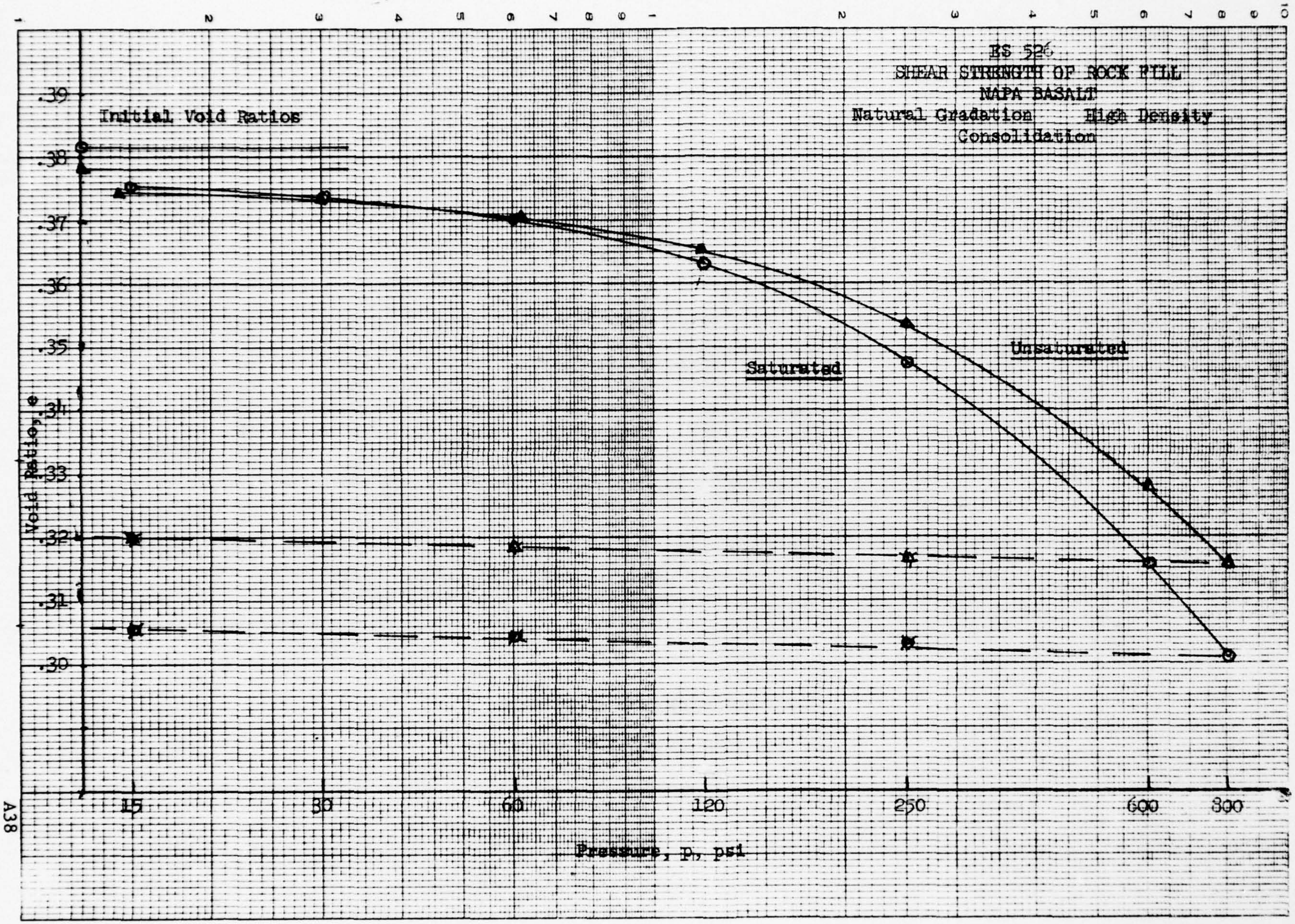
END
DATE
FILMED
9-77
DDC

ES 526

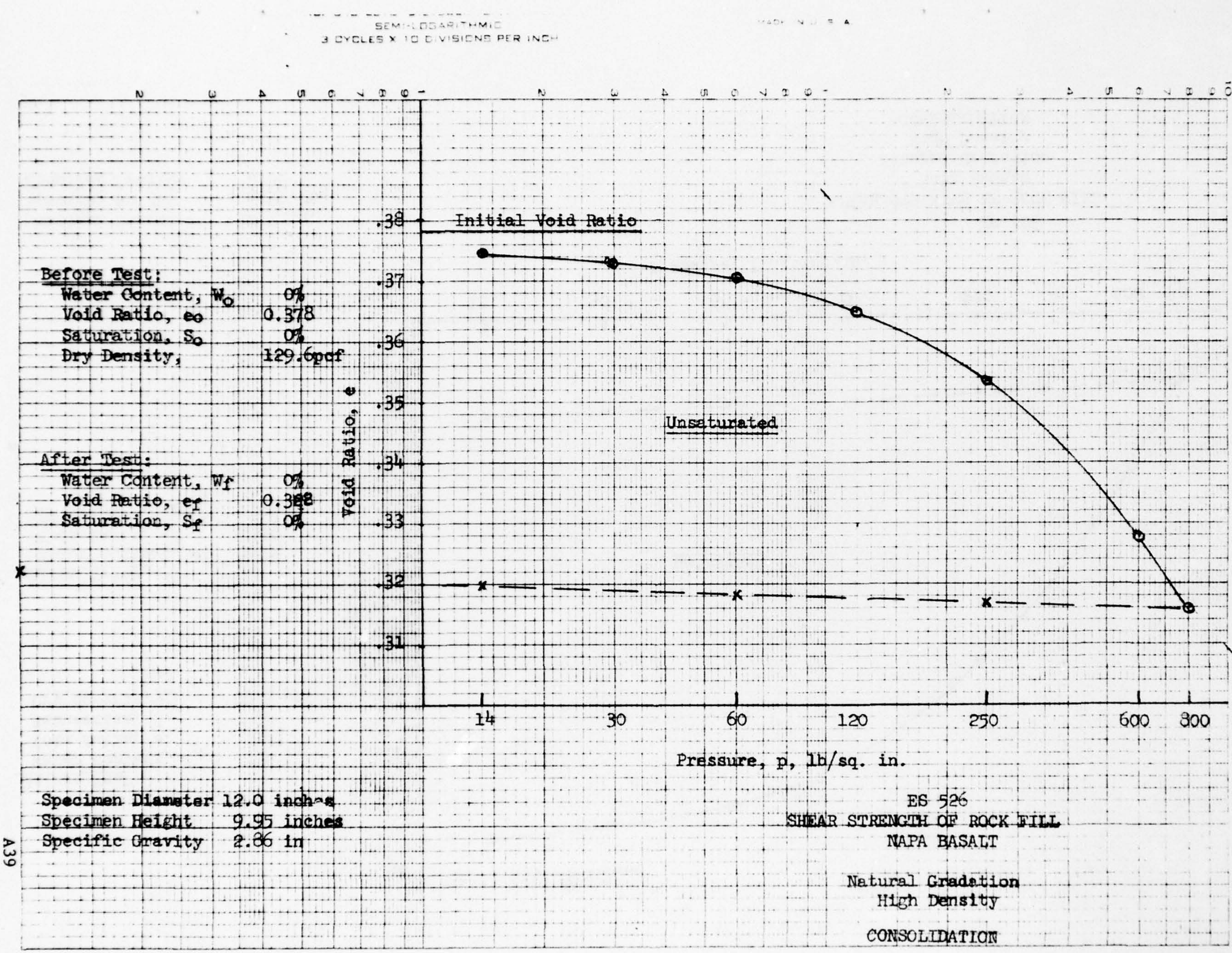
SHEAR STRENGTH OF ROCK FILL

SUMMARY OF CONSOLIDATION TESTS

Material		Sonora Dolomite		Laurel Sandstone		Buchanan Granite		Black Butte Gravel	
Condition		Dry	Saturated	Dry	Saturated	Dry	Saturated	Dry	Saturated
Initial Density, pcf		132.5	132.6	110.9	110.9	118.9	118.0	130.6	130.9
Initial Saturation, %		0	0	0	0	0	0	0	0
Final Saturation, %		0	87	0	75	0	94	0	100
Load, psi		Cumulative consolidation in Percent of Initial Height							
	15	0.15	0.27	0.28	0.61	0.26	0.22	0.25	0.38
Submerged	15	-	0.29	-	0.63	-	0.23	-	0.39
	30	0.23	0.38	0.40	0.80	0.43	0.37	0.35	0.56
	60	0.35	0.52	0.56	1.04	0.73	0.61	0.51	0.86
	120	0.59	0.79	0.92	1.42	1.37	1.33	0.82	1.36
	250	1.42	2.17	1.83	2.85	3.02	3.22	1.46	2.37
	600	3.69	4.82	5.38	6.42	6.56	8.02	2.96	4.52
	800	4.82	6.10	6.74	8.61	8.07	10.48	3.72	5.44
Rebound	0	3.84	5.21	6.11	7.83	7.42	9.84	2.61	4.41



ES 526
SHEAR STRENGTH OF ROCK FILL
NAPA BASALT
Natural Gradation High Density
Consolidation
Initial Void Ratios
Saturated
Unsaturated
Void Ratio, e
.39
.38
.37
.36
.35
.34
.33
.32
.31
.30
15
30
60
120
250
600
800
Pressure, p, psi


SEMI-LOGARITHMIC
3 CYCLES X 10 DIVISIONS PER INCH
Before Test:
Water Content, W_o 0%
Void Ratio, e_o 0.378
Saturation, S_o 0%
Dry Density, 129.6pcf
After Test:
Water Content, W_f 0%
Void Ratio, e_f 0.318
Saturation, S_f 0%
Void Ratio, e
.38
.37
.36
.35
.34
.33
.32
.31
Initial Void Ratio
Unsaturated
14
30
60
120
250
600
800
Pressure, p, lb/sq. in.
Specimen Diameter 12.0 inches
Specimen Height 9.95 inches
Specific Gravity 2.86 in
ES 526
SHEAR STRENGTH OF ROCK FILL
NAPA BASALT
Natural Gradation
High Density
CONSOLIDATION

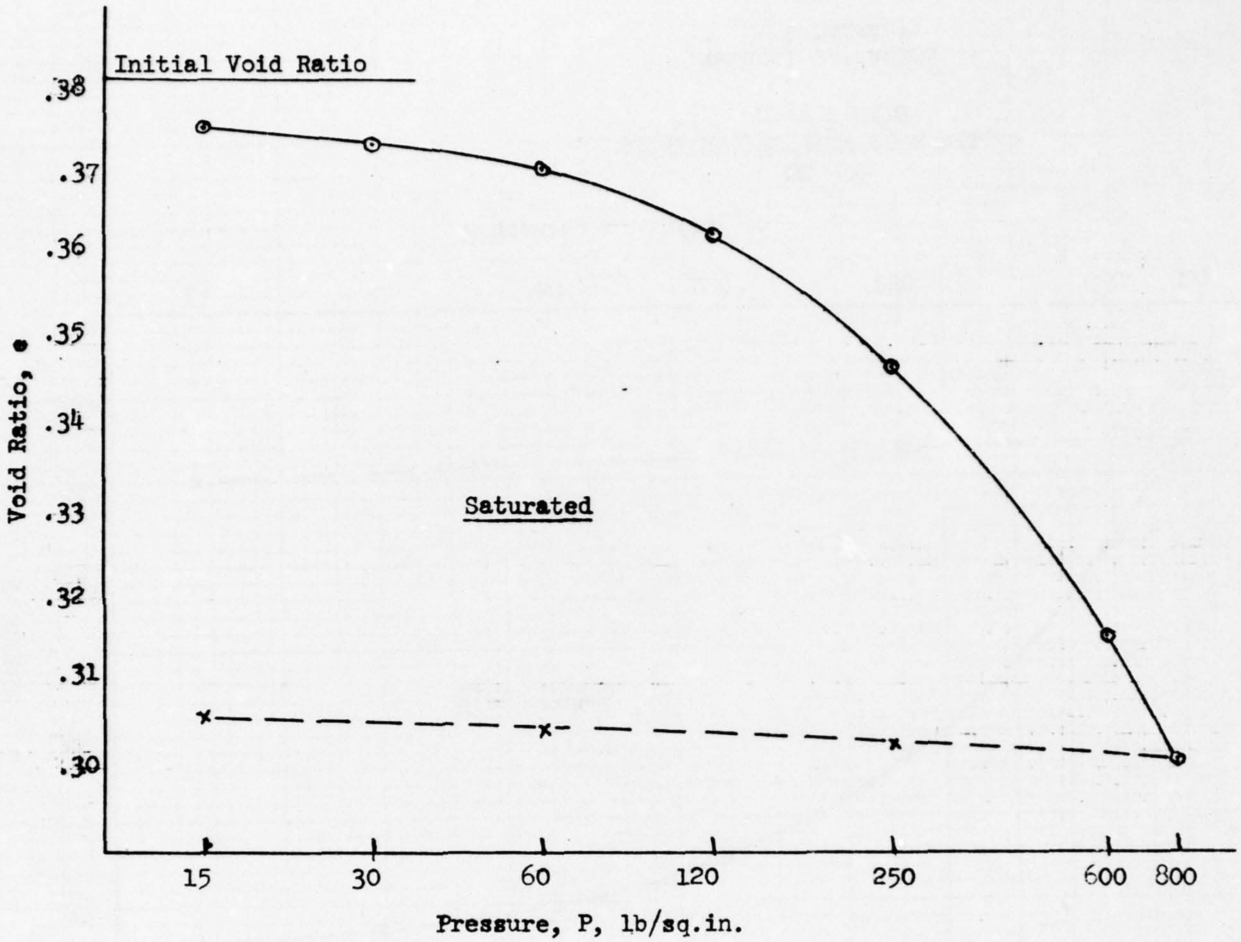
Before Test:

Water Content, W_o	0%
Void Ratio, e_o	.382
Saturation, S_o	0%
Dry Density, γ_d	129.3 pcf

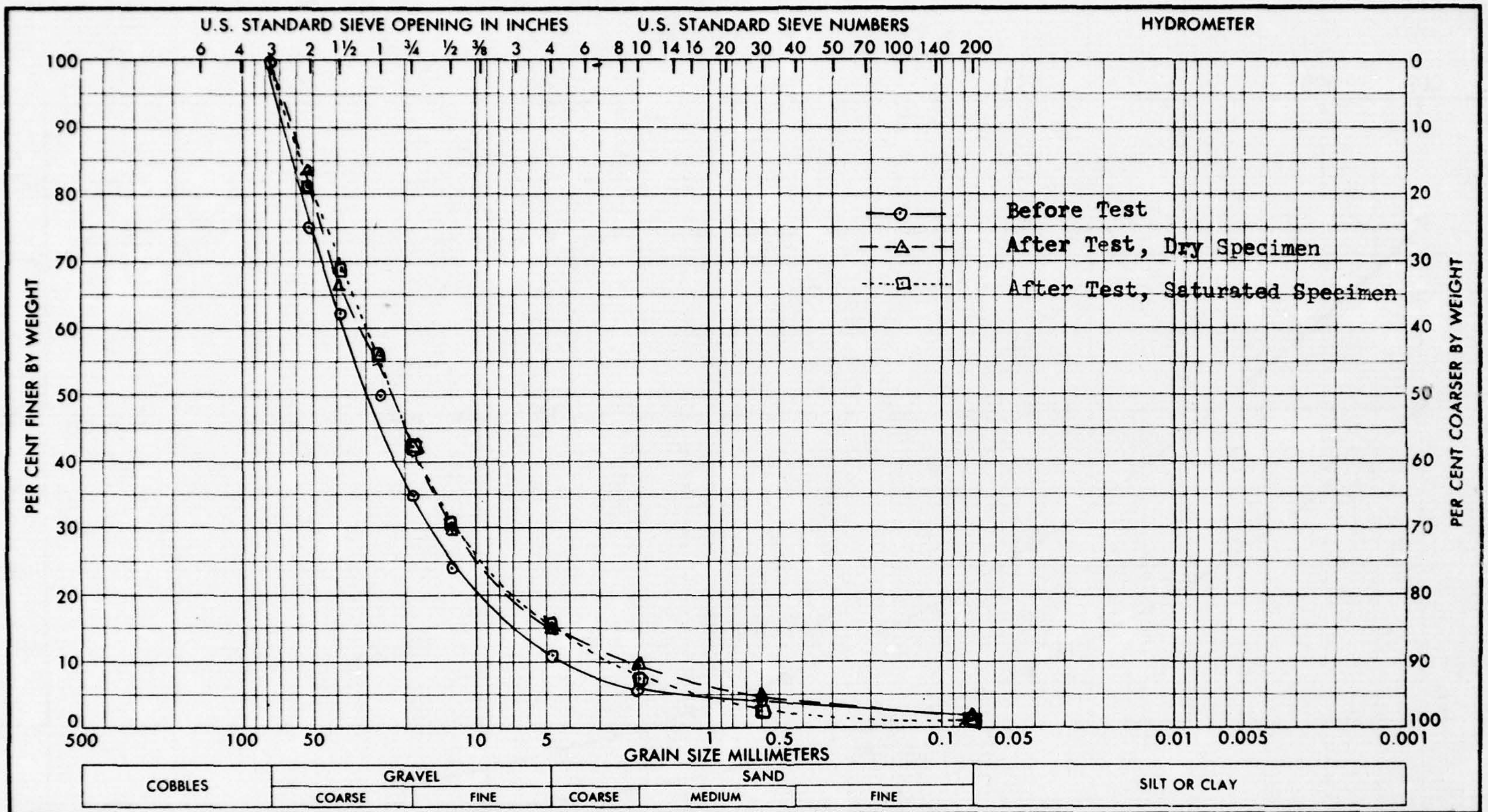
After Test:

Water content, wf	5.1%
Void Ratio, ef	.310
Saturation, S_f	99%

Specimen Diameter	12.0 in.
Specimen Height	9.98 in.
Specific Gravity	2.86



ES 526
SHEAR STRENGTH OF ROCK FILL
NAPA BASALT
Natural Gradation
High Density
CONSOLIDATION



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

GRADATION CURVES

PROJECT ES 526

SHEAR STRENGTH OF ROCK FILL

AREA Napa Basalt

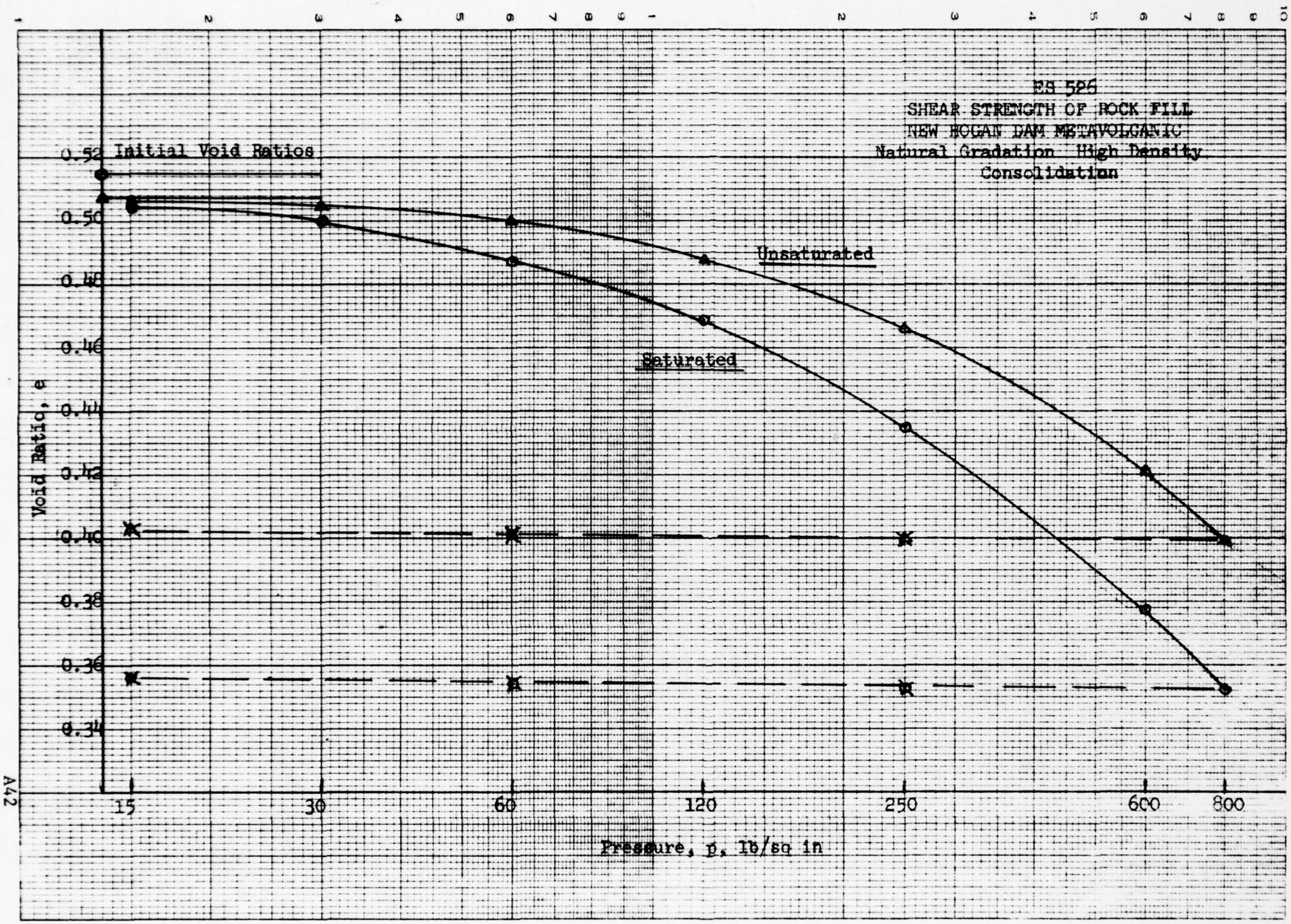
BORING NO. Natural Gradation

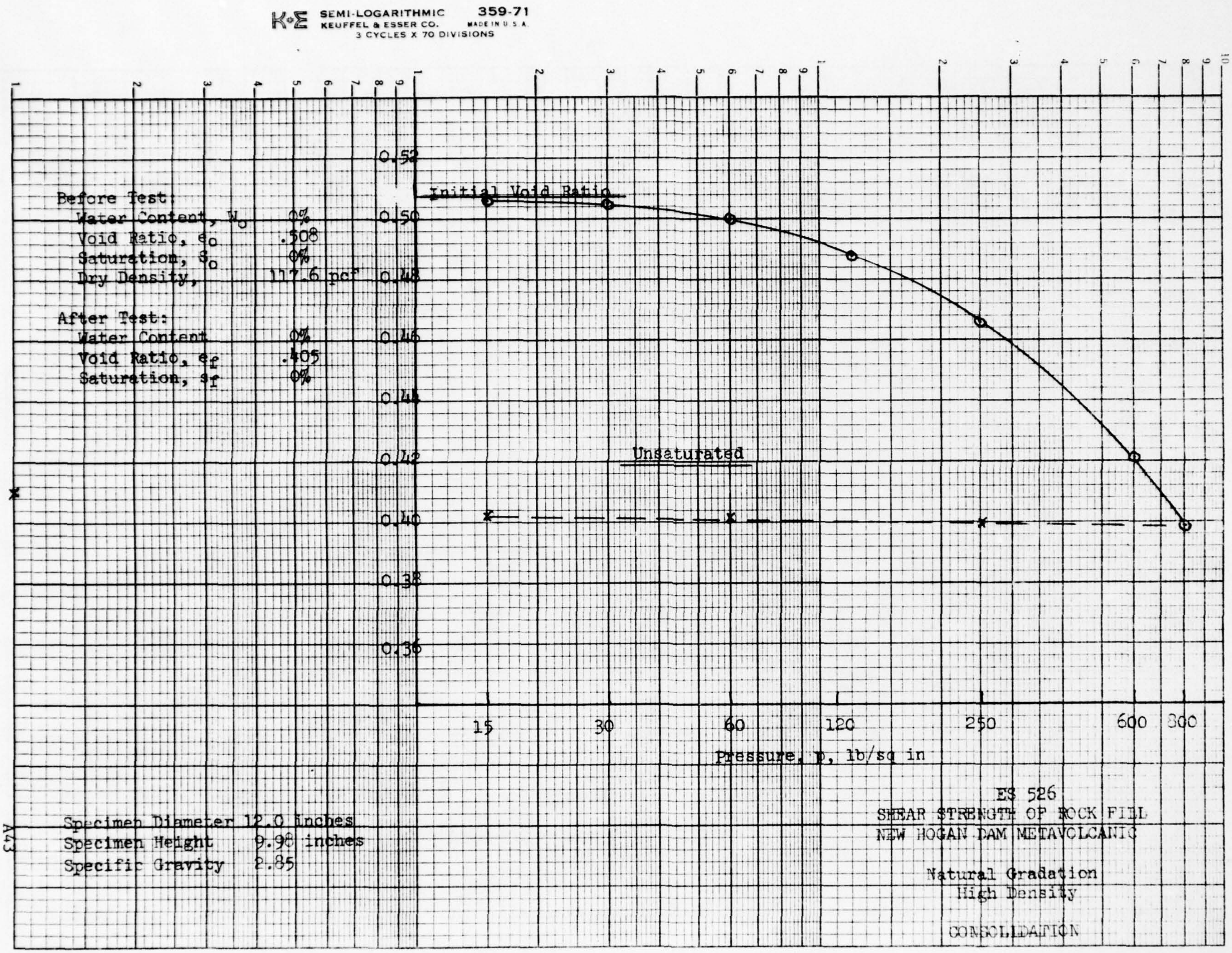
DATE CONSOLIDATION

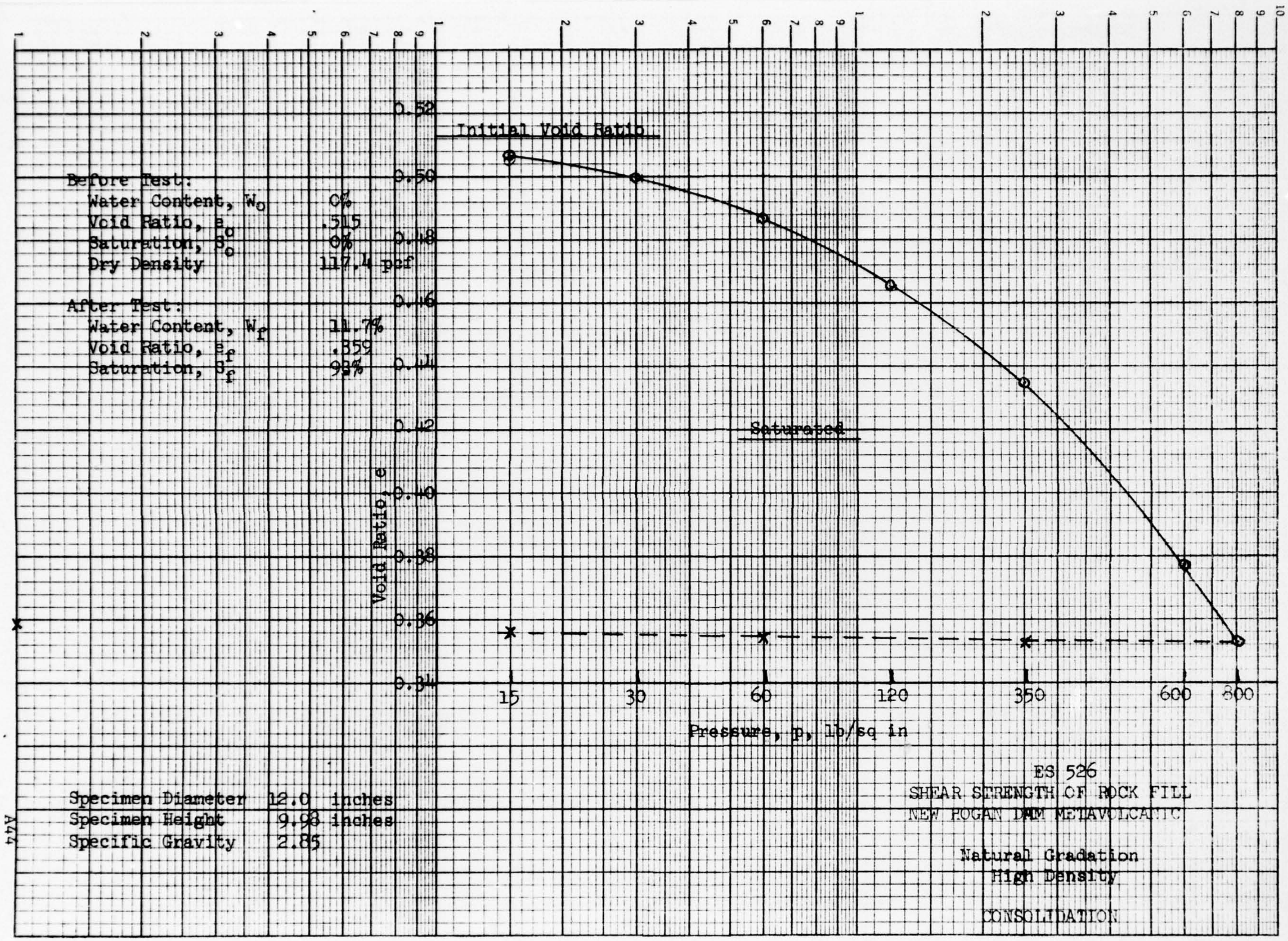
ENG FORM 2087 REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE. (TRANSLUCENT)
1 MAY 63

U.S. GOVERNMENT PRINTING OFFICE 1963 OF—709-126

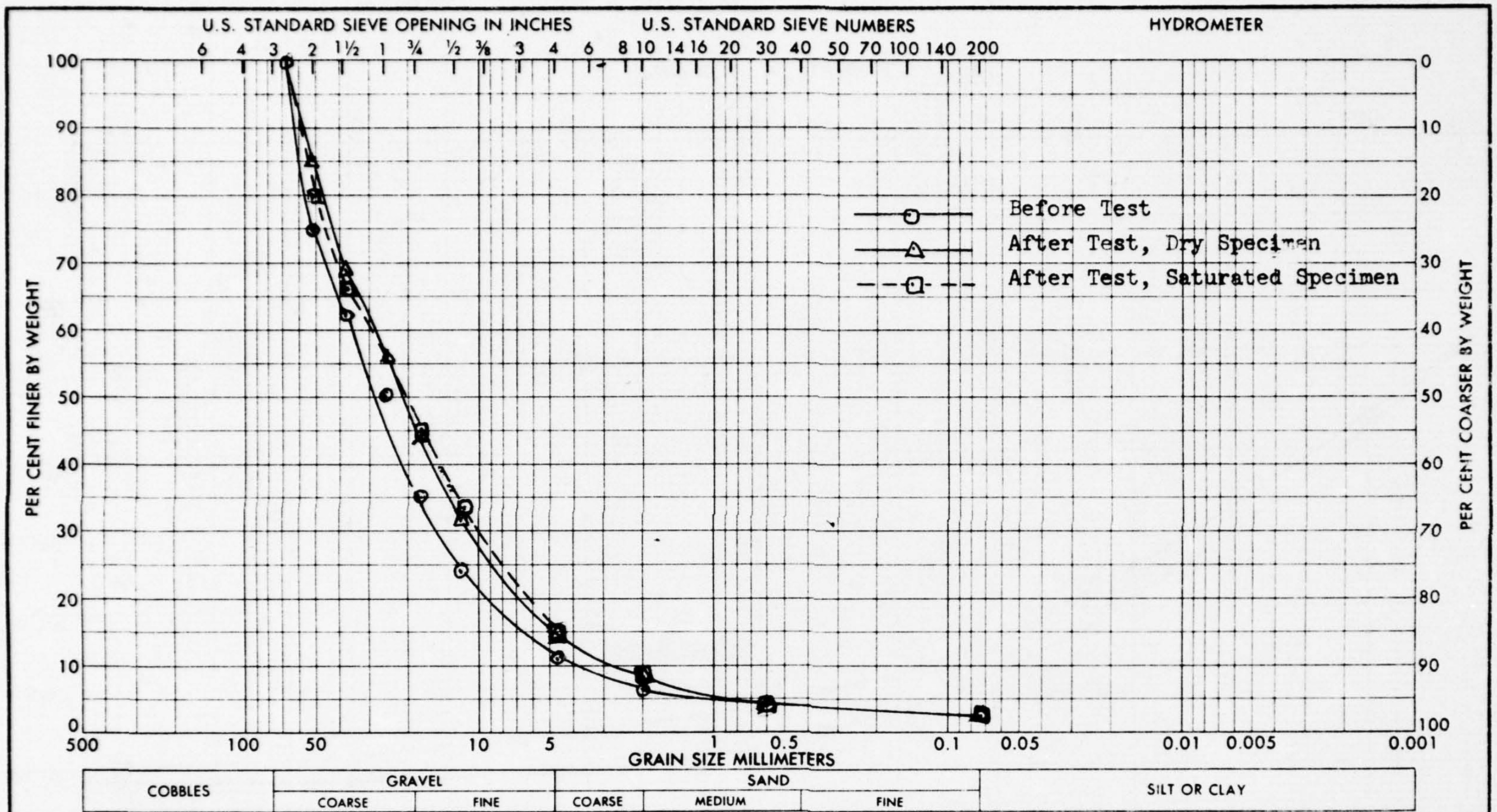
2 CYCLES X 20 DIVISIONS PER INCH




K+E SEMI-LOGARITHMIC 359-71
KEUFFEL & ESSER CO. MADE IN U.S.A.
3 CYCLES X 70 DIVISIONS
Before Test:
Water Content, W_o 0%
Void Ratio, e_o .508
Saturation, S_o 0%
Dry Density, 117.6 pcf
After Test:
Water Content 0%
Void Ratio, e_f .405
Saturation, S_f 0%
0.52
0.50
0.48
0.46
0.44
0.42
0.40
0.38
0.36
Initial Void Ratio
Unsaturated
15
30
60
120
250
600
800
Pressure, p, lb/sq in
Specimen Diameter 12.0 inches
Specimen Height 9.98 inches
Specific Gravity 2.85
ES 526
SHEAR STRENGTH OF ROCK FILL
NEW HOGAN DAM METAVOLCANIC
Natural Gradation
High Density
CONSOLIDATION



Initial Void Ratio
Before Test:
Water Content, W_o 0%
Void Ratio, e_o .515
Saturation, S_o 0%
Dry Density 117.4 pcf
After Test:
Water Content, W_f 11.7%
Void Ratio, e_f .359
Saturation, S_f 93%
Saturated
Void Ratio, e
0.52
0.50
0.48
0.46
0.44
0.42
0.40
0.38
0.36
0.34
15
30
60
120
350
600
800
Pressure, p, lb/sq in
Specimen Diameter 12.0 inches
Specimen Height 9.98 inches
Specific Gravity 2.85
ES 526
SHEAR STRENGTH OF ROCK FILL
NEW POGAN DAM METAVOLCANIC
Natural Gradation
High Density
CONSOLIDATION



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

PROJECT ES 526

SHEAR STRENGTH OF ROCK FILL

~~AREA~~ New Hogan Metavolcanic

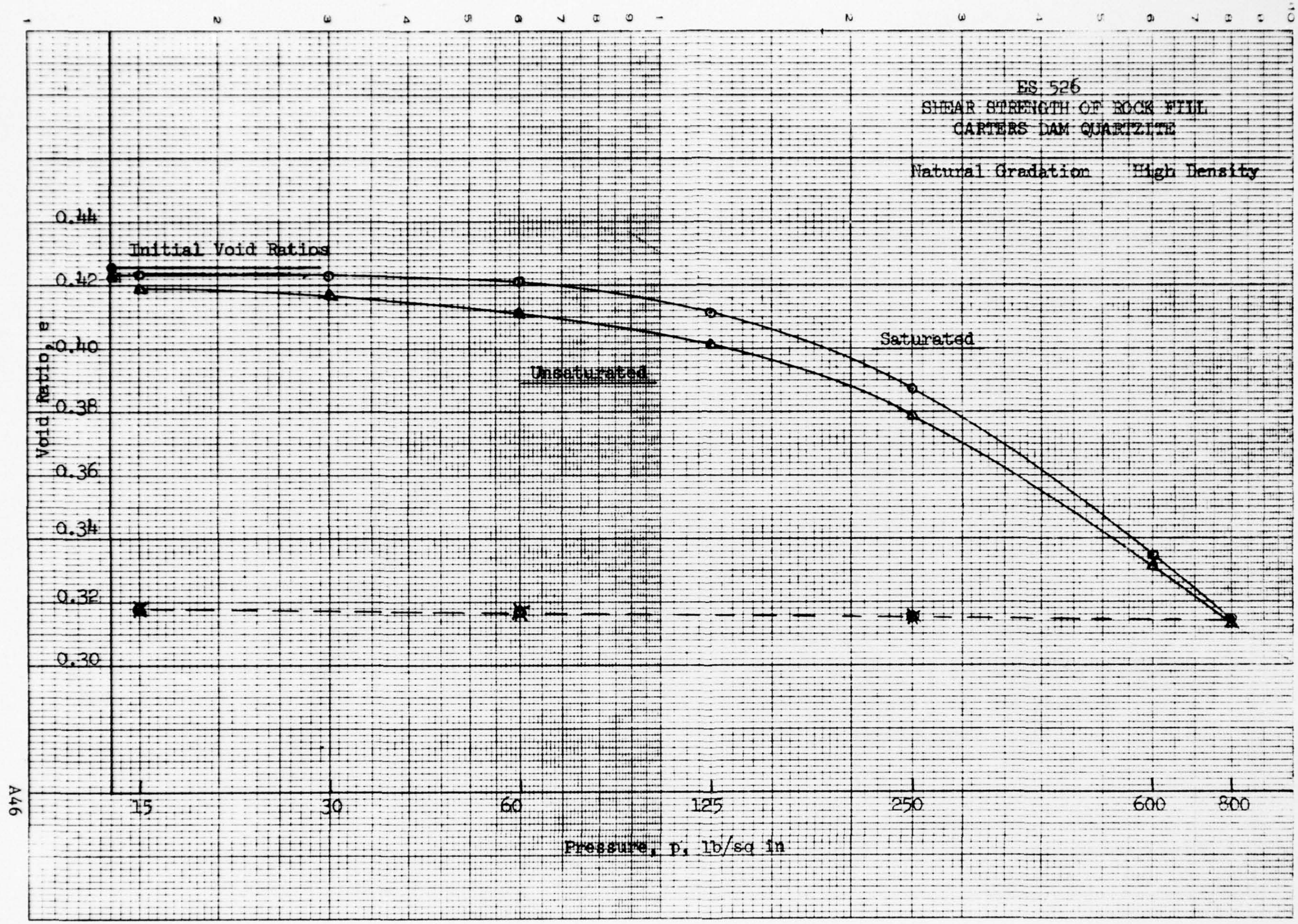
~~BORING NO.~~ Natural Gradation

~~DATE~~ Consolidation

GRADATION CURVES

ENG FORM 1 MAY 63 **2087** REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE. (*TRANSLUCENT*)

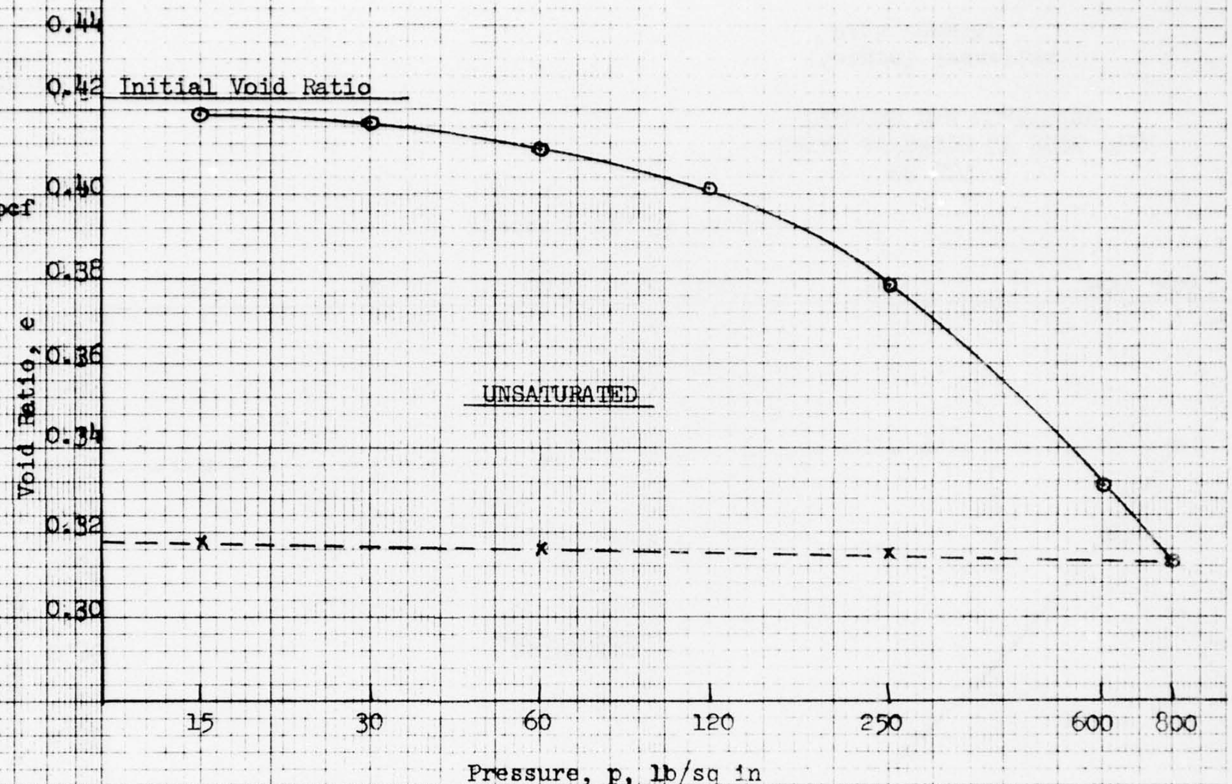
U.S. GOVERNMENT PRINTING OFFICE 1963 OF—709-126


ES 526
SHEAR STRENGTH OF ROCK FILL
CARTERS DAM QUARTZITE
Natural Gradation High Density
Initial Void Ratios
Saturated
Unsaturated
Void Ratio, e
0.44
0.42
0.40
0.38
0.36
0.34
0.32
0.30
15
30
60
125
250
600
800
Pressure, p, lb/sq in

SEMI-LOGARITHMIC
3 CYCLES X 10 DIVISIONS PER INCH

Before Test:
- Water Content, W_o — 0%
- Void Ratio, e_o — .423
- Saturation, S_o — 0%
- Dry Density, — 119.7 pcf

After Test:
- Water Content, W_f — 0%
- Void Ratio, e_f — .321
- Saturation, S_f — 0%



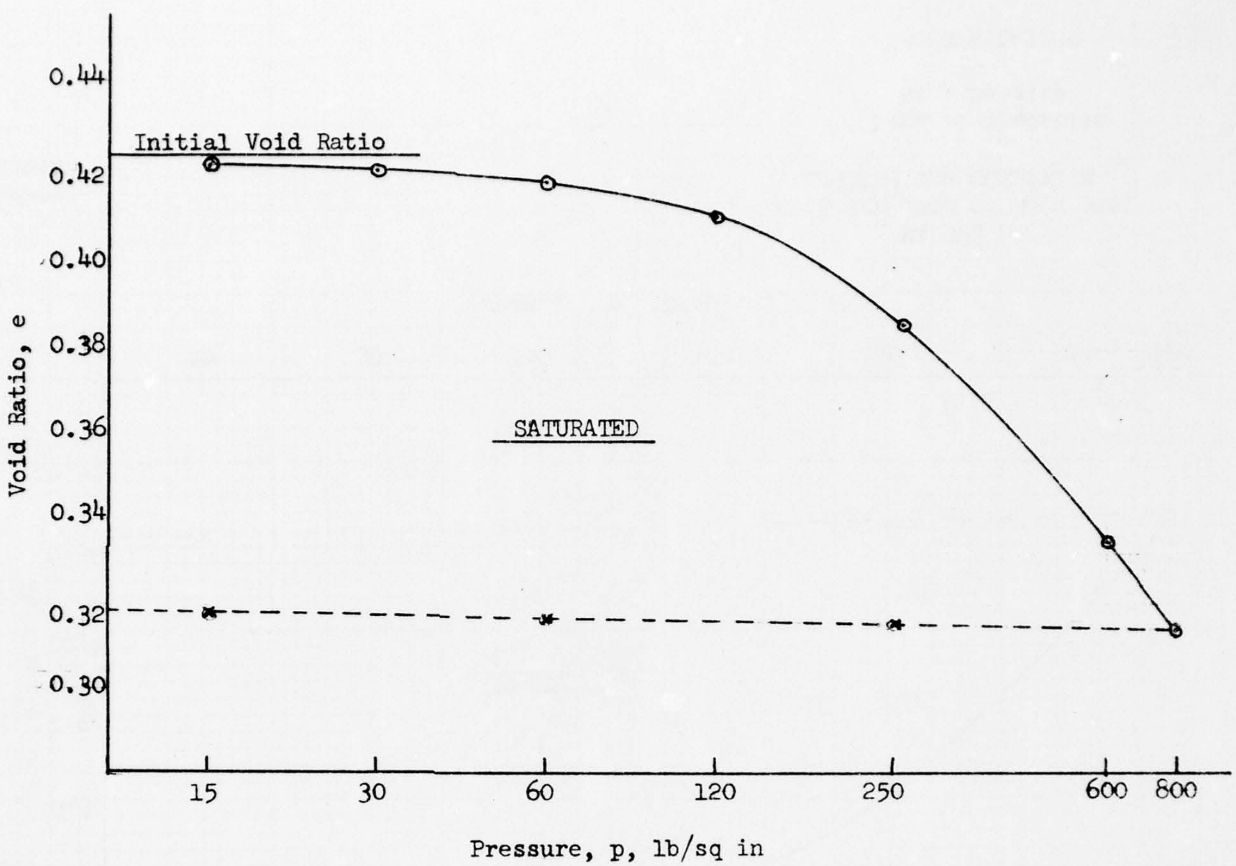
Specimen Diameter	12.0 inches
Specimen Height	9.98 inches
Specific Gravity	2.73

ES 526
SHEAR STRENGTH OF ROCK FILL
CARTERS DAM QUARTZITE

Natural Gradation
High Density

CONSOLIDATION

Before Test:	
Water Content, W_o	0%
Void Ratio, e_o	.426
Saturation, S_o	0%
Dry Density, γ_d^o	119.5pcf
After Test:	
Water Content, W_f	10.5%
Void Ratio, e_f	.321
Saturation, S_f	90%

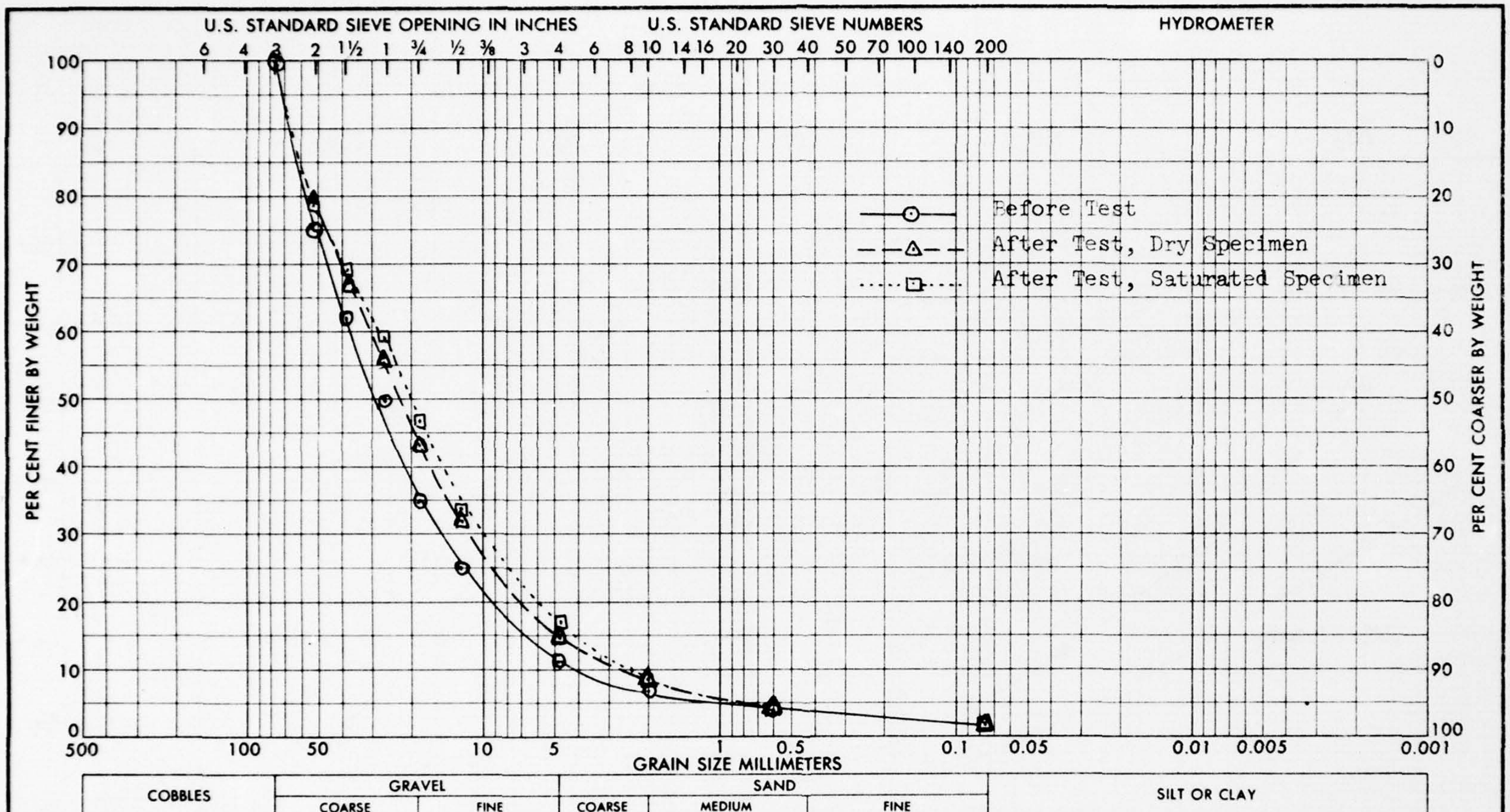


ES 526
SHEAR STRENGTH OF ROCK FILL
CARTERS DAM QUARTZITE

Natural Gradation
High Density

CONSOLIDATION

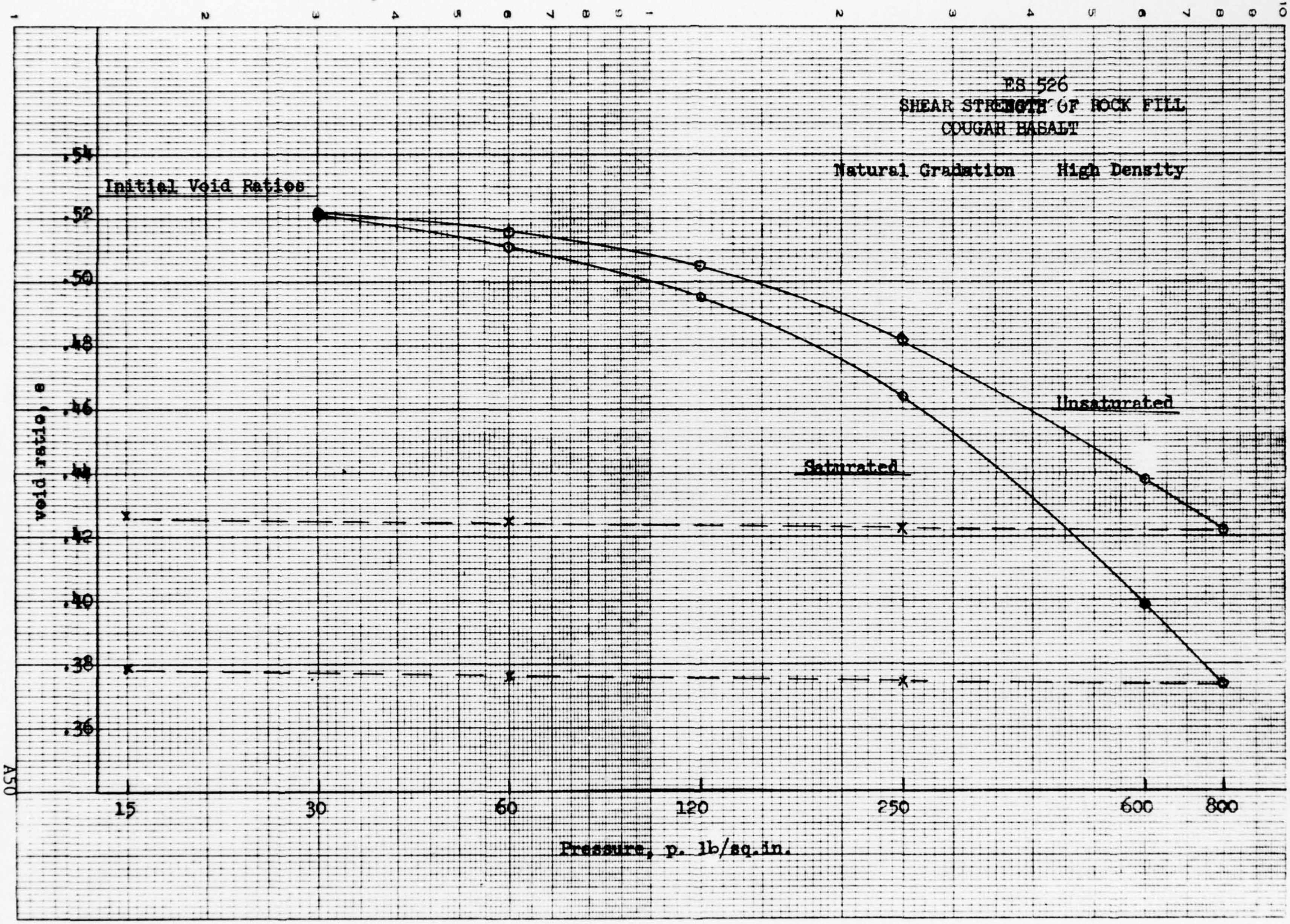
Specimen Diameter	12.0 inches
Specimen Height	9.98 inches
Specific Gravity	2.73



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI	PROJECT ES 526
							SHEAR STRENGTH OF ROCK FILL
							AREA Carters Dam Quartzite
							BORING NO. Natural Gradation
GRADATION CURVES							DATE Consolidation

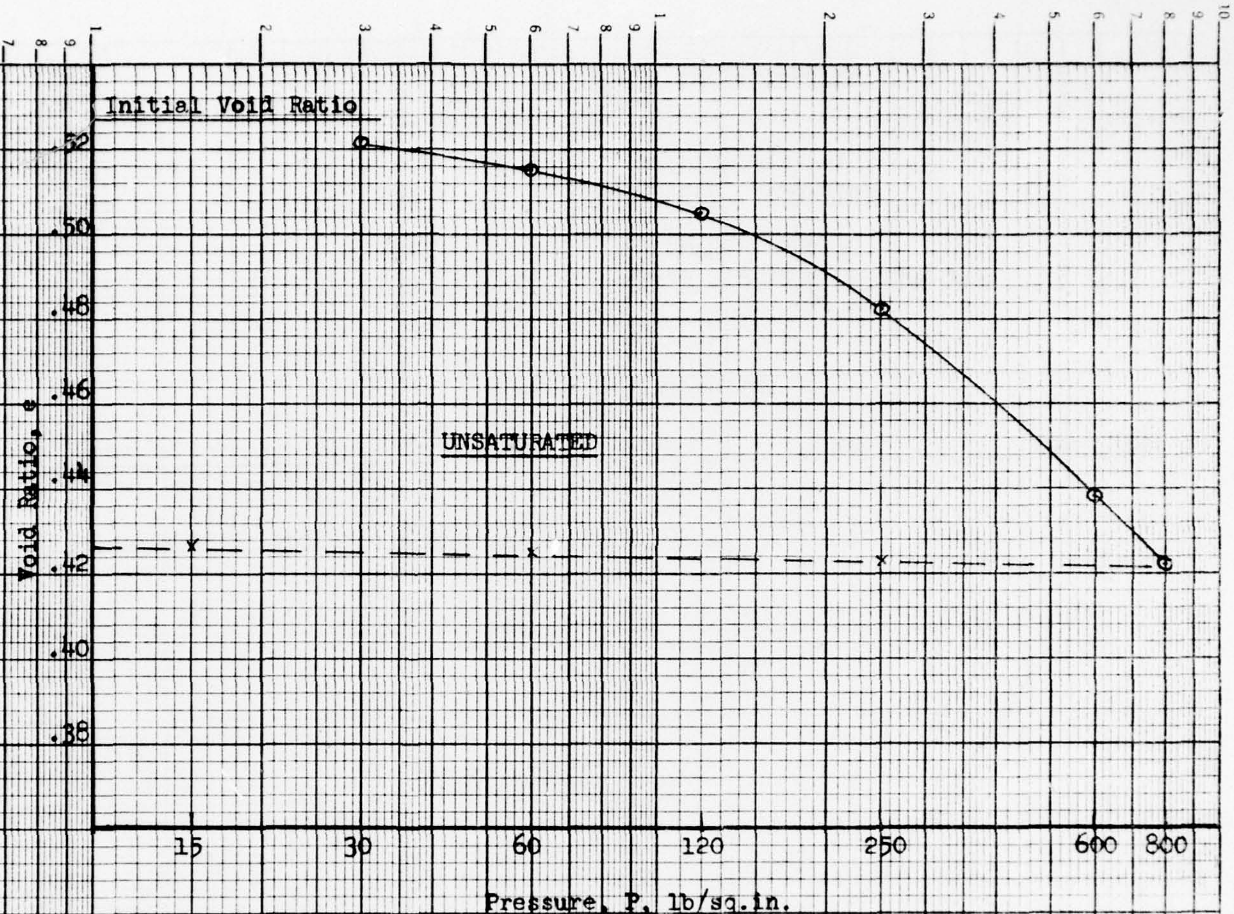
ENG FORM 1 MAY 63 **2087** REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE. *(TRANSLUCENT)*

U.S. GOVERNMENT PRINTING OFFICE : 1963 OF—709-126



ES 526
SHEAR STRENGTH OF ROCK FILL
COUGAR BASALT
Natural Gradation
High Density
Initial Void Ratios
Unsaturated
Saturated
void ratio, e
.54
.52
.50
.48
.46
.44
.42
.40
.38
.36
15
30
60
120
250
600
800
Pressure, p. lb/sq.in.

KEUFFEL & ESSER CO. MADE IN U.S.A.
3 CYCLES X 70 DIVISIONS



Before Test:
Water Content, Wo	0 %
Void Ratio, e_o	.527
Saturation S_o	0%
Dry Density, γ_d	112.0 pcf

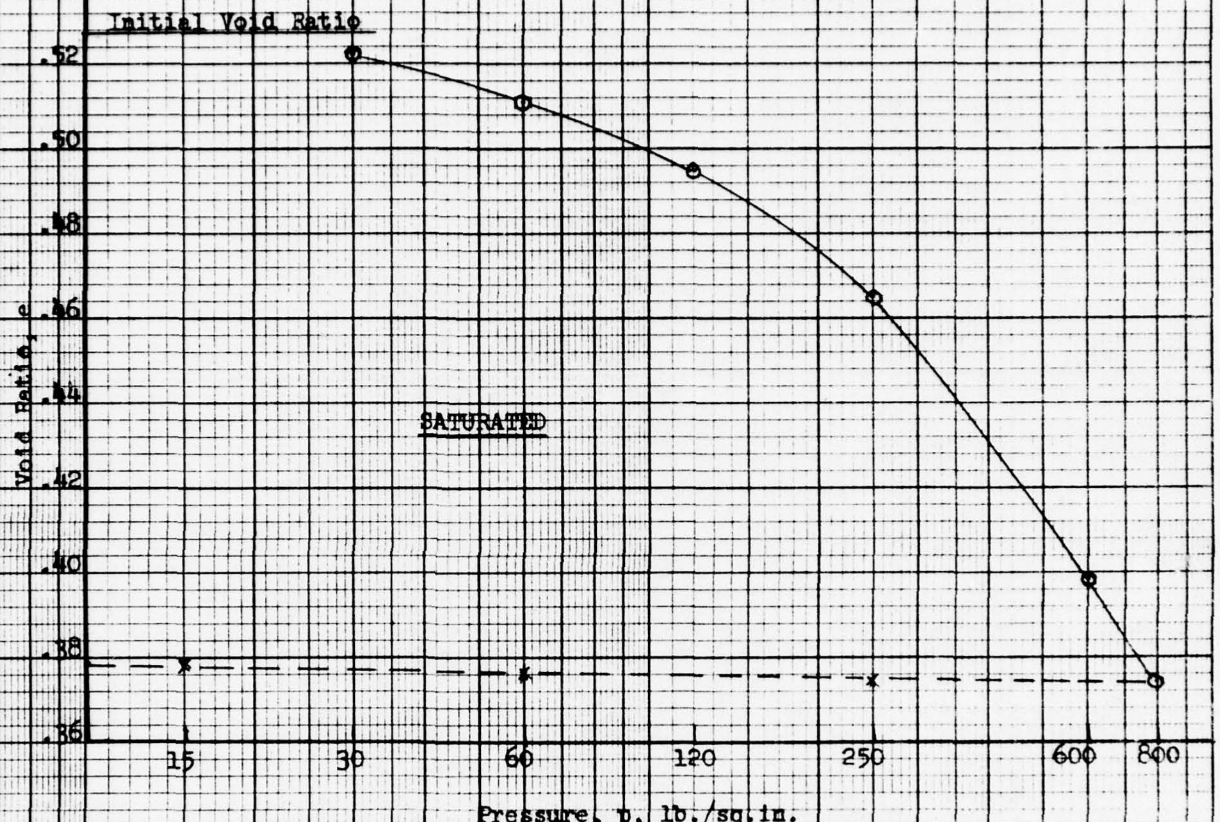
After Test:
Water Content, W_f	0%
Void Ratio, e_f	.431
Saturation, S_f	0%

Specimen Diameter	12.0 inches
Specimen Height	9.95 inches
Specific Gravity	2.74

ES 526
SHEAR STRENGTH OF ROCK FILL
COUGAR BASALT

Natural Gradation
High Density

CONSOLIDATION



Before Test:
Water Content, W_o 0%
Void Ratio, e_o .527
Saturation, S_o 0%
Dry Density, γ_d 112.0 pcf

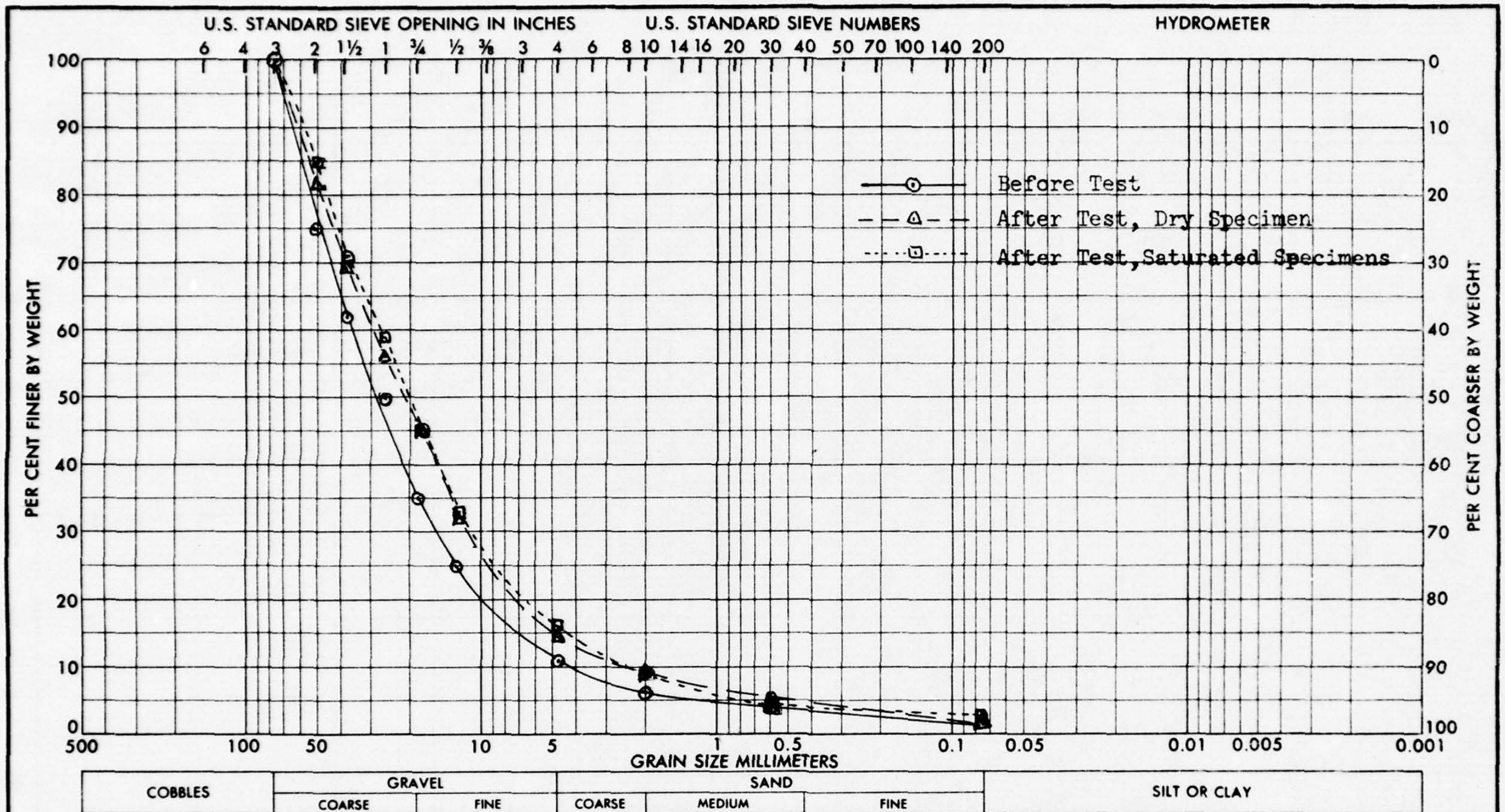
After Test:
Water Content, W_f 12.9%
Void Ratio, e_f .381
Saturation, S_f 93%

Specimen Diameter 12 inches
Specimen Height 10.05 inches
Specific Gravity 2.74

ES 526
SHEAR STRENGTH OF ROCK FILL
COUGAR BASALT

Natural Gradation
High Density

CONSOLIDATION



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

PROJECT ES 526

SHEAR STRENGTH OF ROCK FILL

AREA Cougar Basalt

BORING NO. Natural Gradation

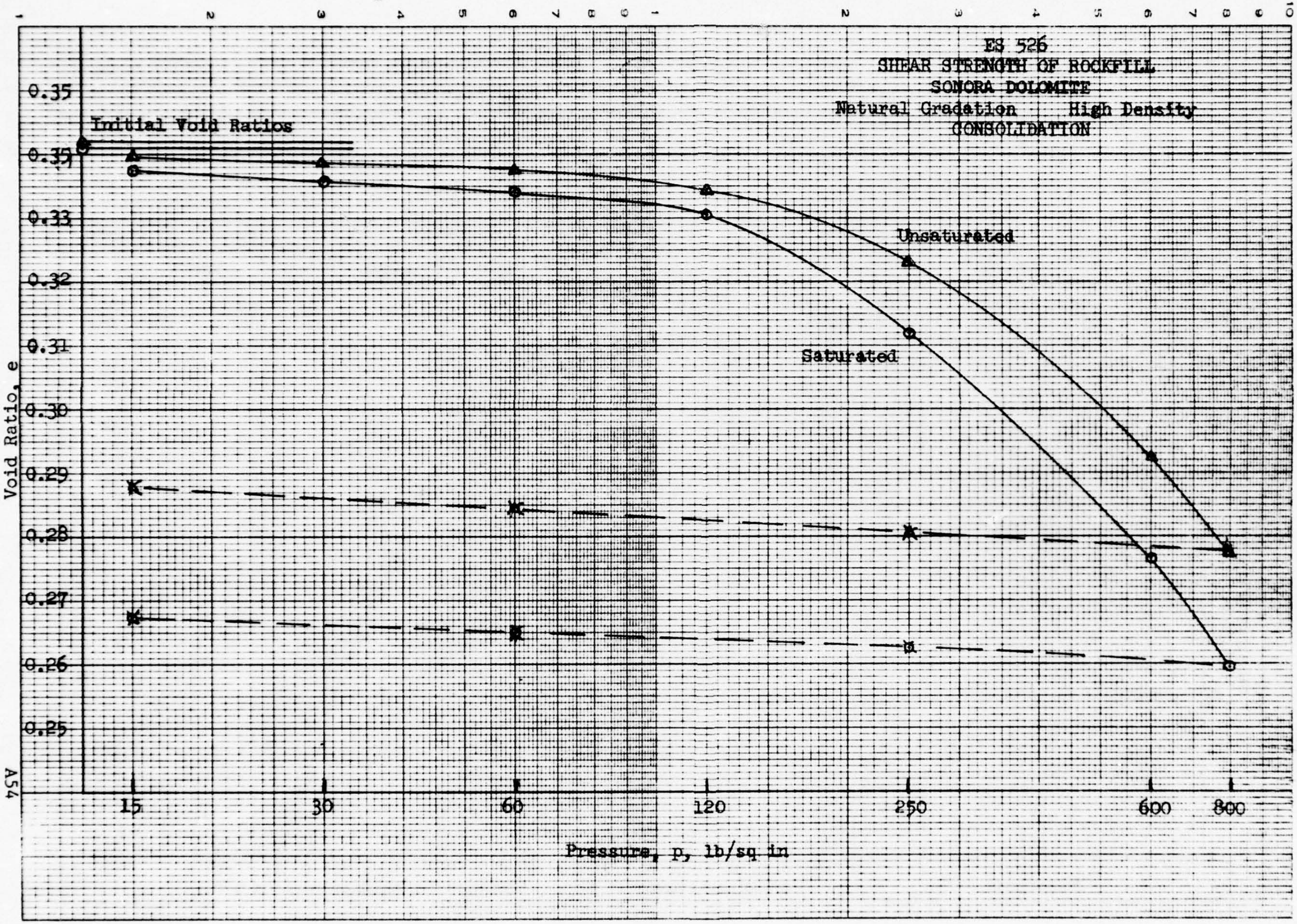
DATE Consolidation

GRADATION CURVES

ENG FORM 2087
1 MAY 63

REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE. (TRANSLUCENT)

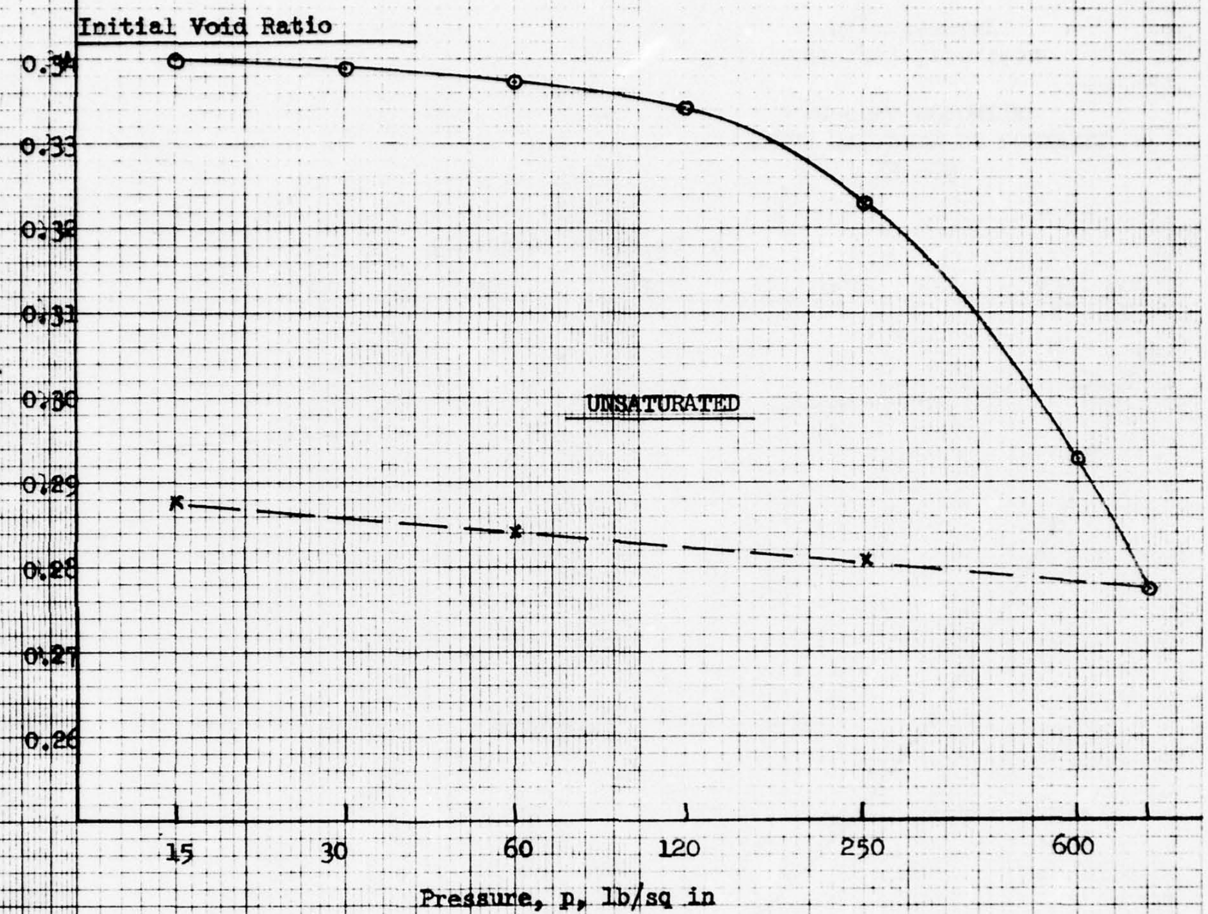
U.S. GOVERNMENT PRINTING OFFICE : 1963 OF—709-126



ES 526
SHEAR STRENGTH OF ROCKFILL
SONORA DOLOMITE
Natural Gradation High Density
CONSOLIDATION
Initial Void Ratios
Unsaturated
Saturated
0.35
0.34
0.33
0.32
0.31
0.30
0.29
0.28
0.27
0.26
0.25
Void Ratio, e
15
30
60
120
250
600
800
Pressure, p, lb/sq in

NO. 340-L310 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC
3 CYCLES X 10 DIVISIONS PER INCH

EUGENE DIETZGEN CO.
MADE IN U.S.A.



Before test:
- Water Content, W_o 0%
- Void Ratio, e_o .342
- Saturation, S_o 0%
- Dry Density, 132.5 pcf

After test:
- Water Content, W_f 0%
- Void Ratio, e_f .290
- Saturation, S_f 0%

Specimen Diameter 12.0 inches
Specimen Height 8.28 inches
Specific Gravity 2.85

ES 526
SHEAR STRENGTH OF ROCK FILL
SONORA DOLOMITE

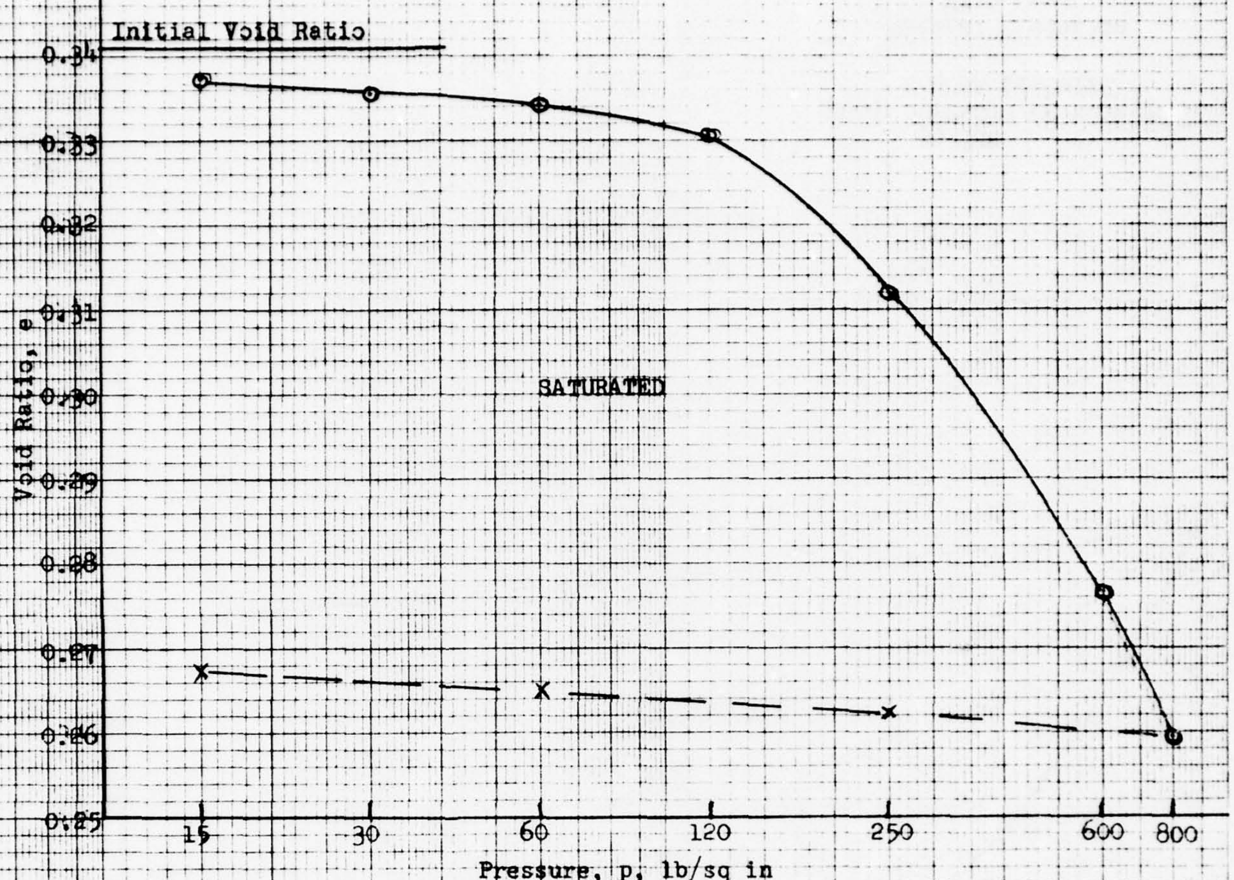
Natural Gradation
High Density
CONSOLIDATION

Before Test:

Water Content, W_o 0%
Void Ratio, e_o .341
Saturation, S_o 0%
Dry Density, γ_d 132.6pcf

After Test:

Water Content, W_f 8.3%
Void Ratio, e_f .271
Saturation, S_f 88%

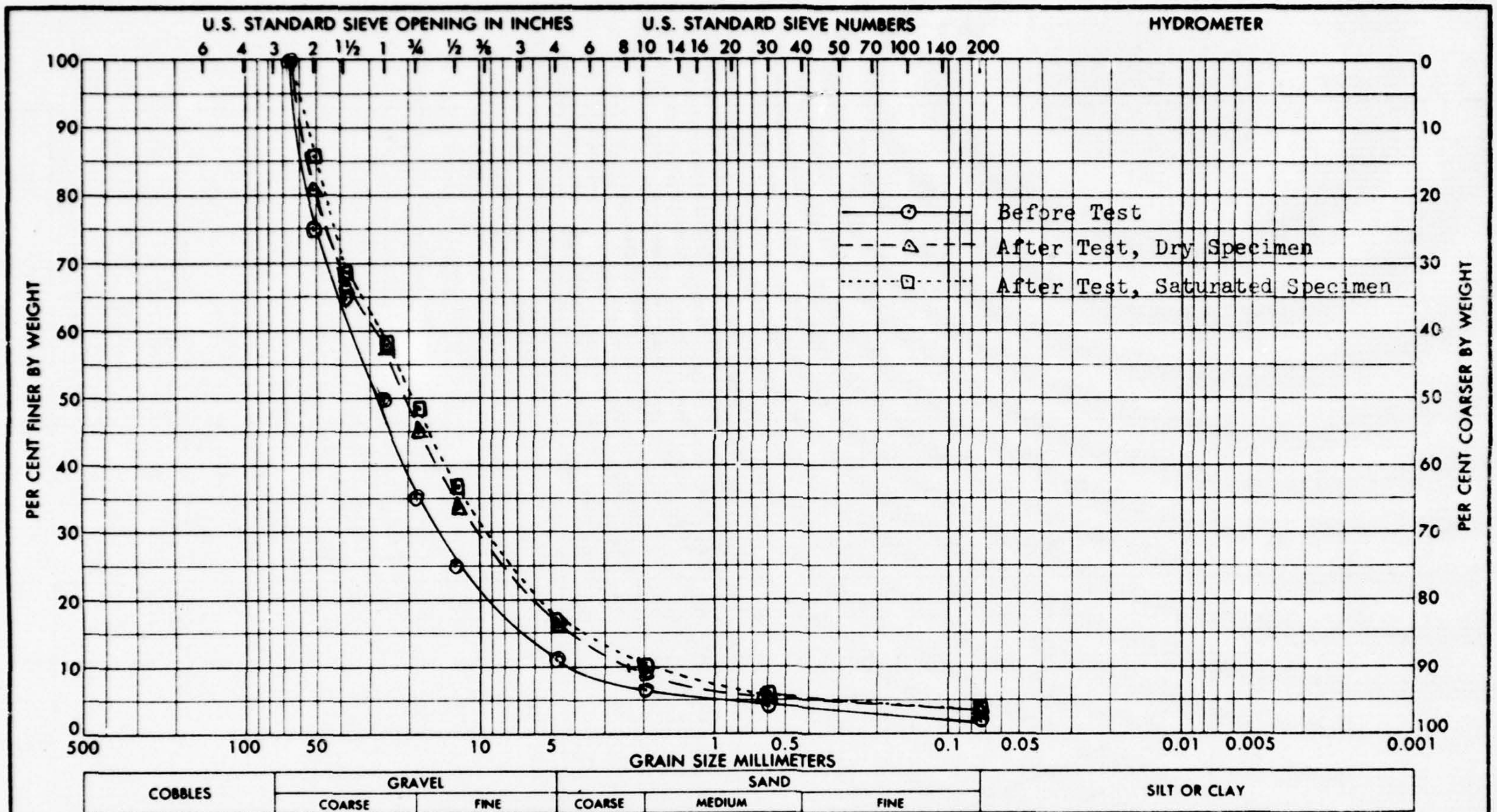


Specimen Diameter 12.0 inches
Specimen Height 8.28 inches
Specific Gravity 2.85

ES 526
SHEAR STRENGTH OF ROCKFILL
SONORA DOLOMITE

Natural Gradation
High Density

CONSOLIDATION



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

GRADATION CURVES

PROJECT ES 526

SHEAR STRENGTH OF ROCK FILL

AREA Sonora Dolomite

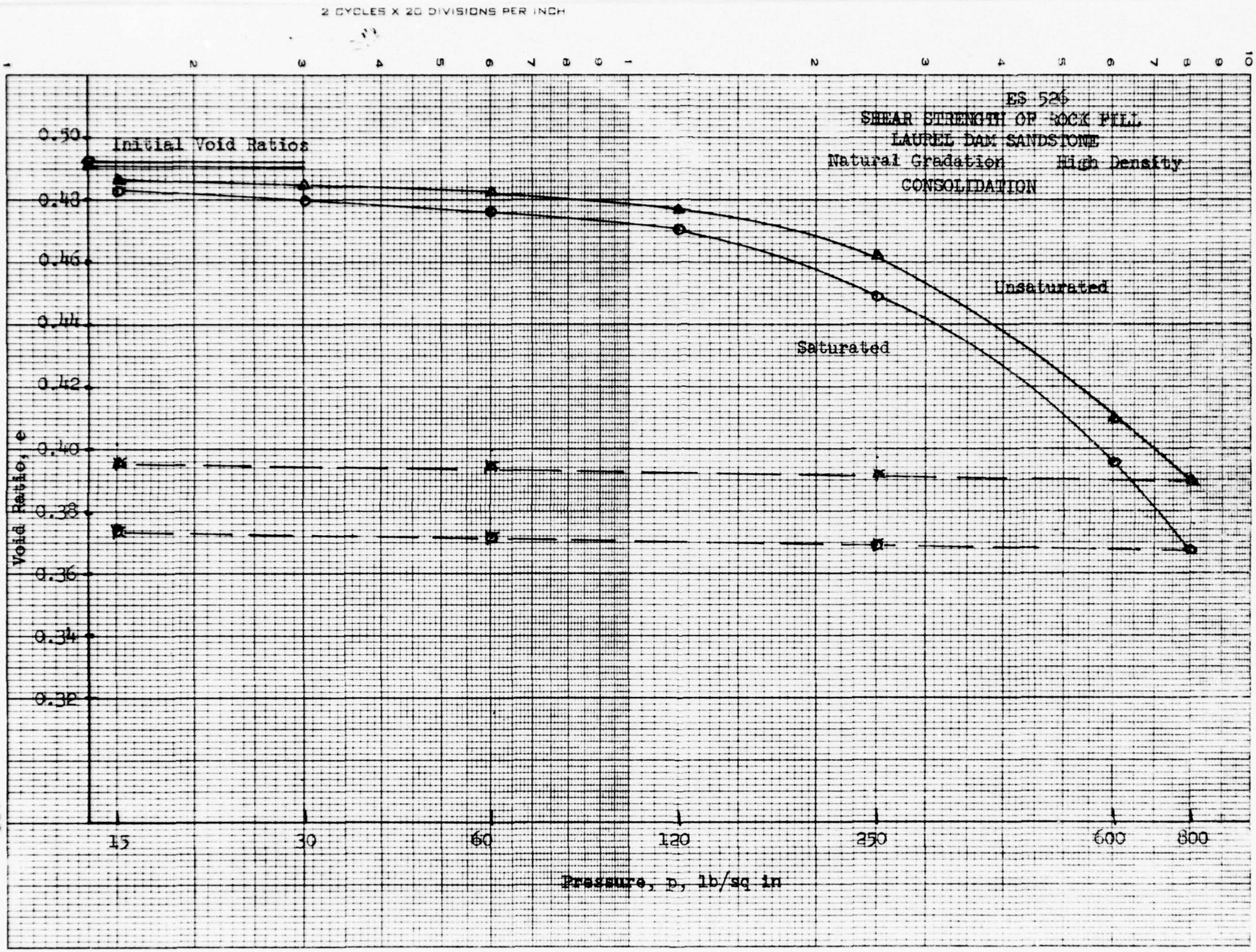
BORING NO. Natural Gradation

DATE Consolidation

ENG FORM 2087
1 MAY 63

REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE.

U.S. GOVERNMENT PRINTING OFFICE 1963 OF—709-124



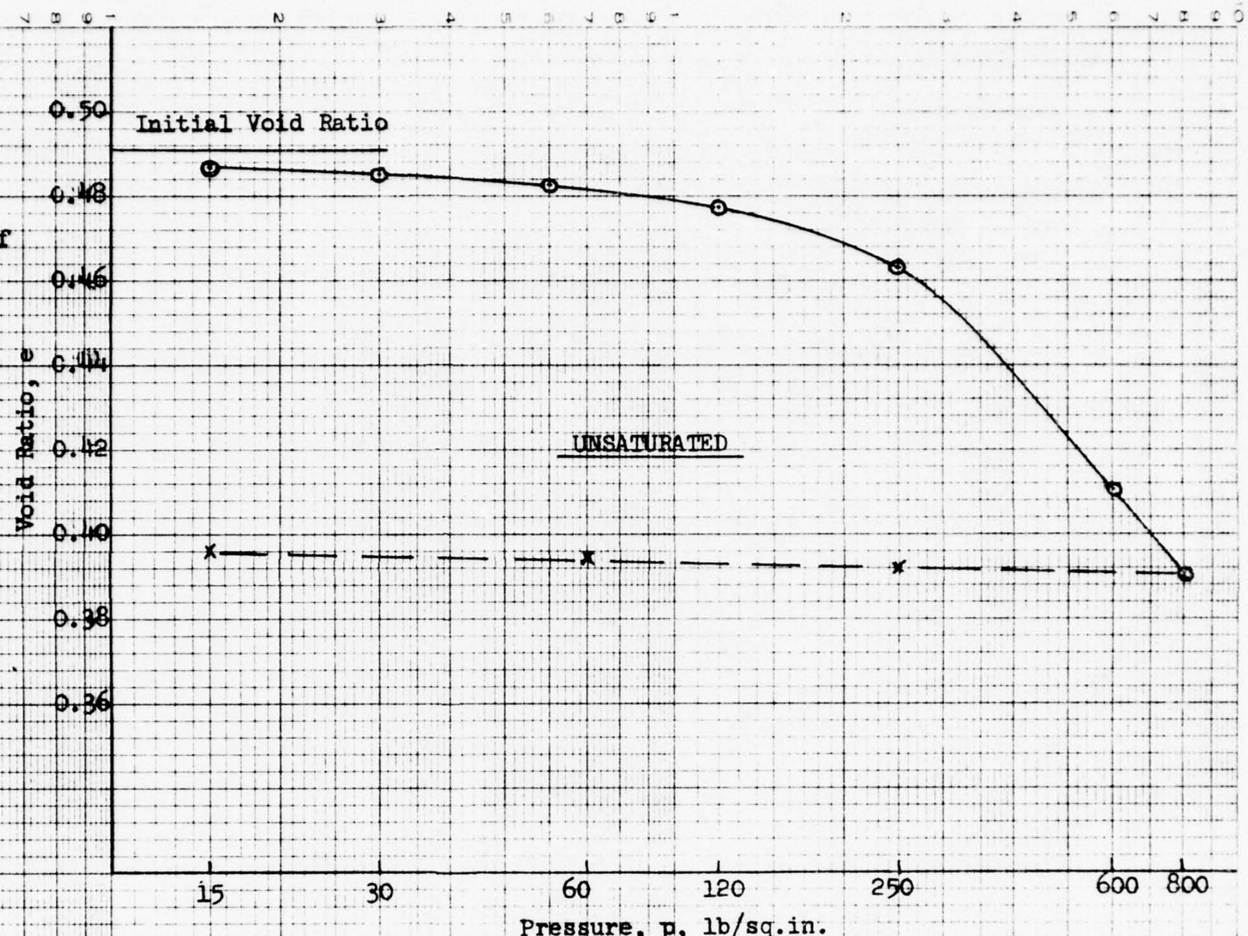
ES 526
SHEAR STRENGTH OF ROCK FILL
LAUREL DAM SANDSTONE
Natural Gradation High Density
CONSOLIDATION
Initial Void Ratios
Unsaturated
Saturated
Void Ratio, e
Pressure, p, lb/sq in
0.50
0.48
0.46
0.44
0.42
0.40
0.38
0.36
0.34
0.32
15
30
60
120
250
600
800
2 CYCLES X 20 DIVISIONS PER INCH

Before Test

Water Content, W_o	0%
Void Ratio, e_o	.491
Saturation, S_o	0%
Dry Density	110.9 pcf

After Test

Water Content, W_f	0%
Void Ratio, e_f	.400
Saturation, S_f	0%

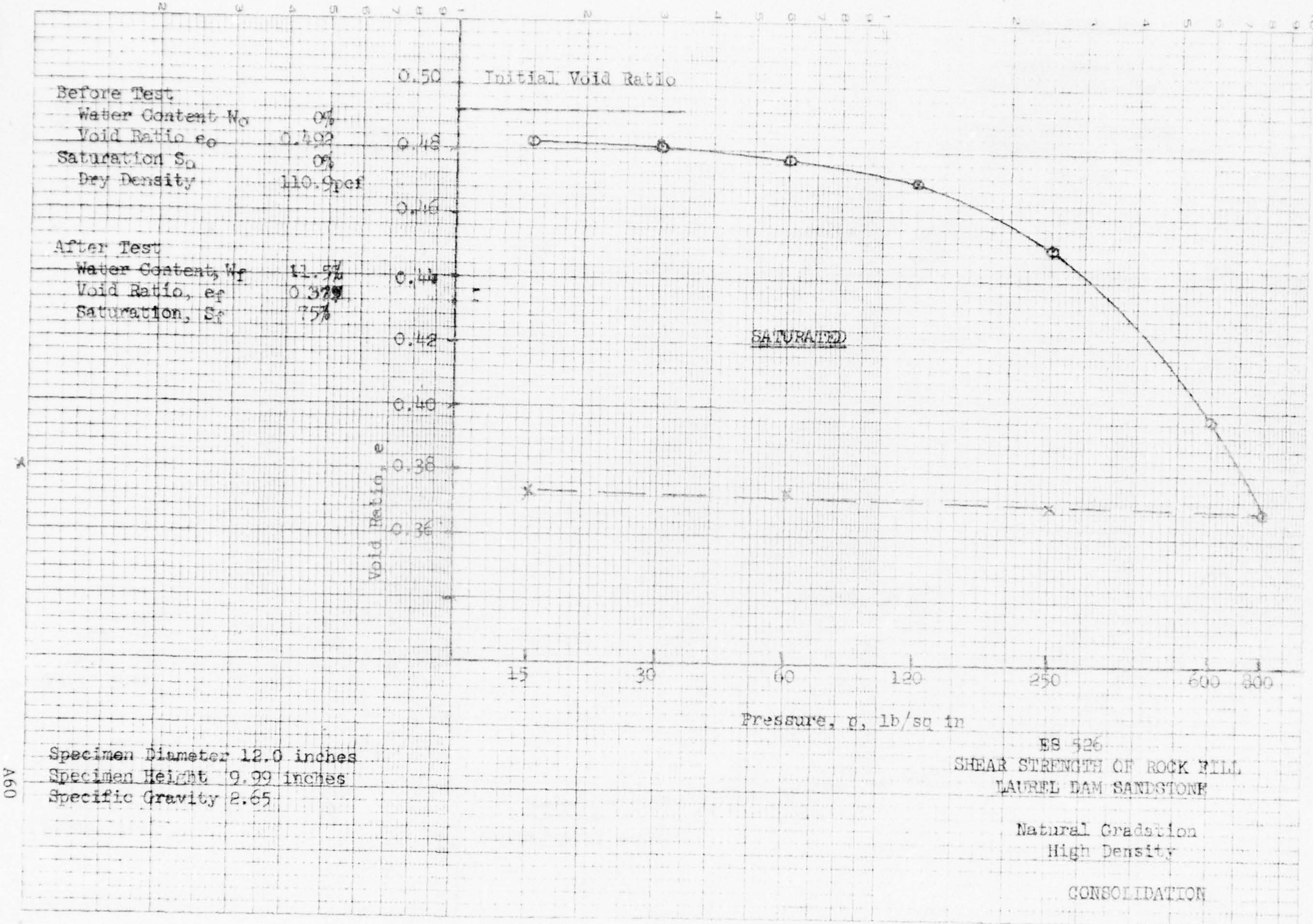


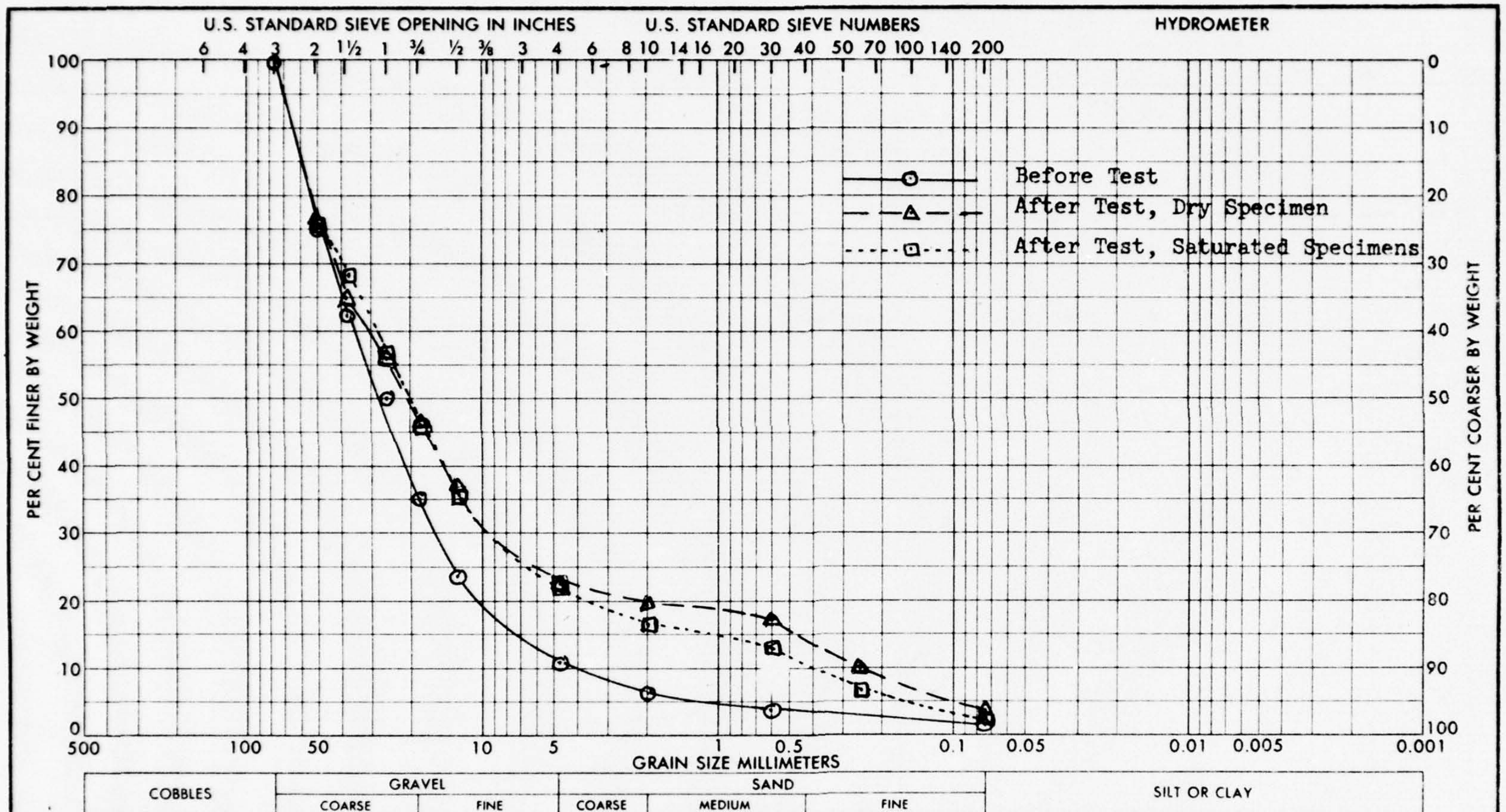
Specimen Diameter	12.0 inches
Specimen Height	9.99 inches
Specific Gravity	2.65

ES 526
SHEAR STRENGTH OF ROCK FILL
LAUREL DAM SANDSTONE

Natural Gradation
High Density

CONSOLIDATION


Before Test
Water Content W_o 0%
Void Ratio e_o 0.492
Saturation S_o 0%
Dry Density 110.9pcf
After Test
Water Content, W_f 11.5%
Void Ratio, e_f 0.37
Saturation, S_f 75%
0.50
Initial Void Ratio
0.48
0.46
0.44
0.42
0.40
0.38
0.36
Void Ratio, e
SATURATED
15
30
60
120
250
600
800
Pressure, p, lb/sq in
Specimen Diameter 12.0 inches
Specimen Height 9.99 inches
Specific Gravity 2.65
ES 526
SHEAR STRENGTH OF ROCK FILL
LAUREL DAM SANDSTONE
Natural Gradation
High Density
CONSOLIDATION



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

PROJECT ES 526

SHEAR STRENGTH OF ROCK FILL

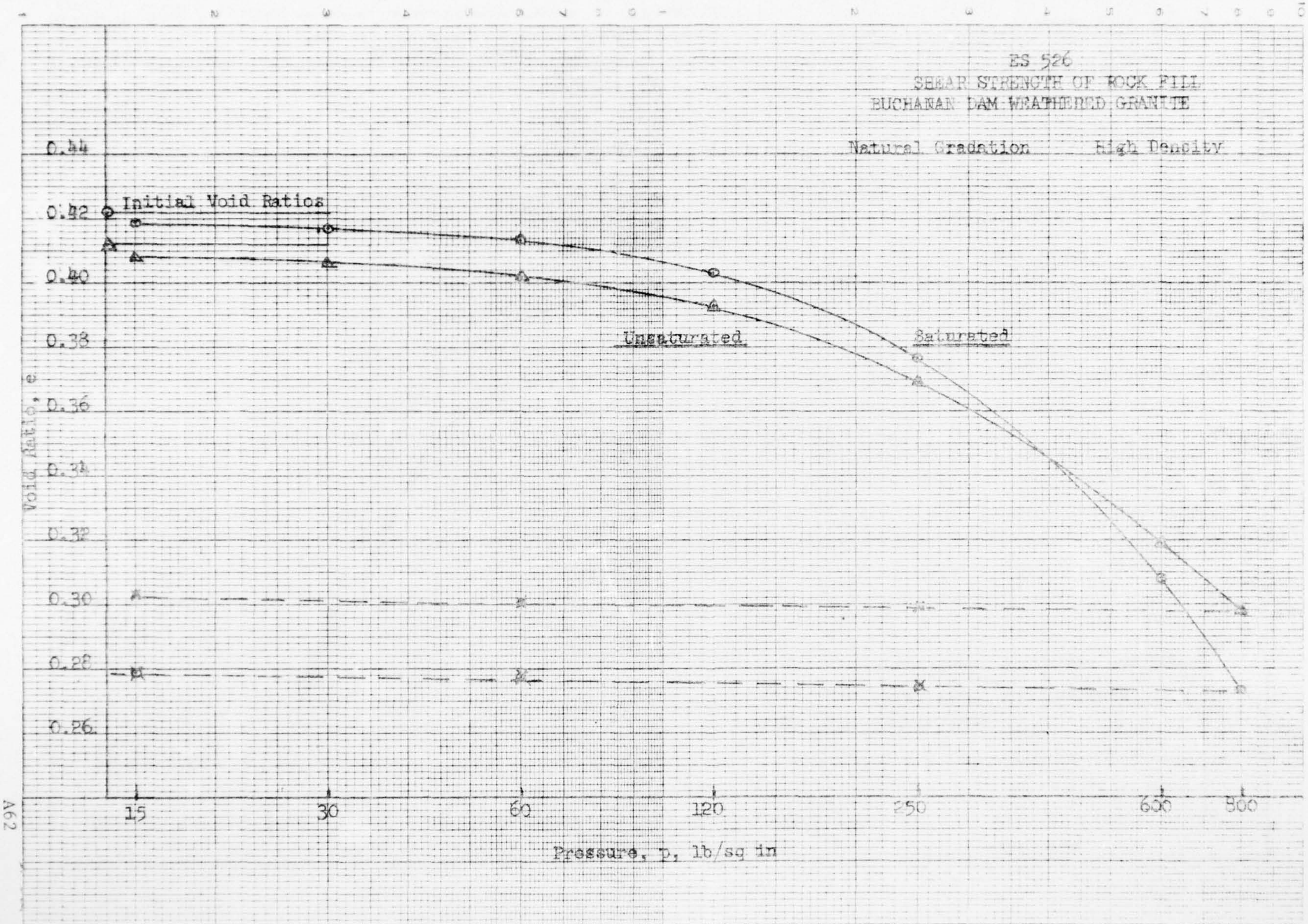
~~AREA~~ Laurel Dam Sandstone

~~BORING NO~~ Natural Gradation

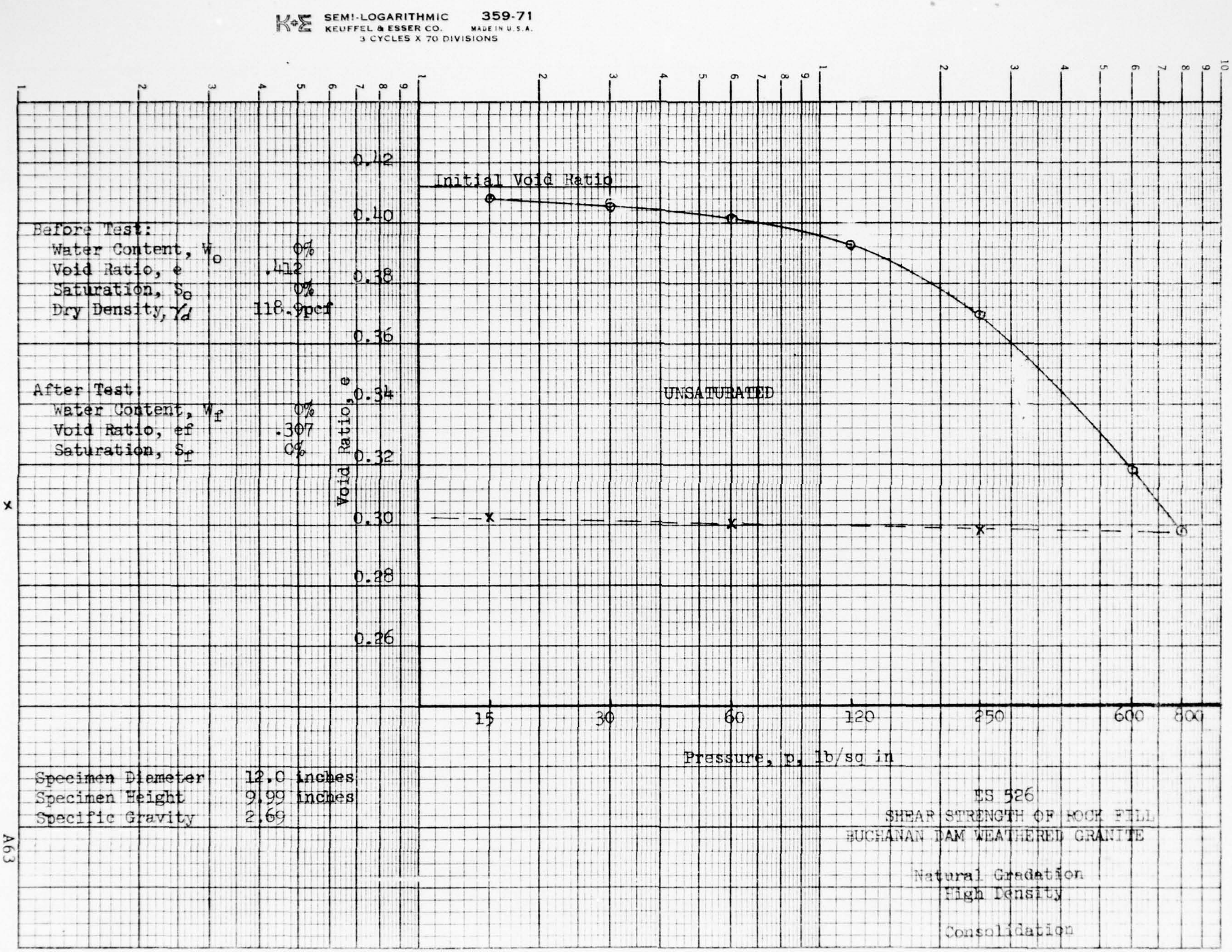
~~DATE~~ Consolidation

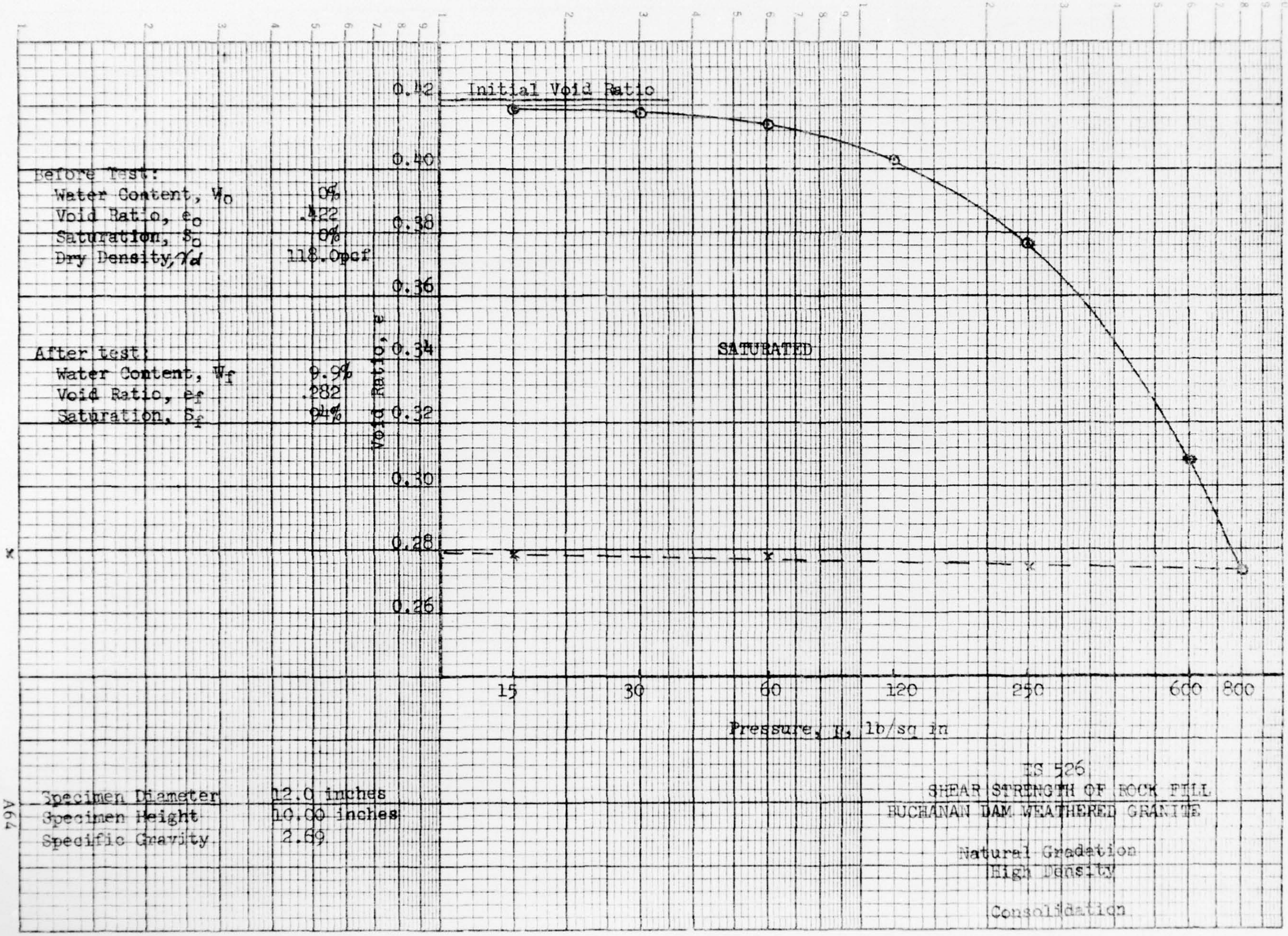
GRADATION CURVES

ENG FORM 2087 REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE (TRANSLUCENT)
1 MAY 63

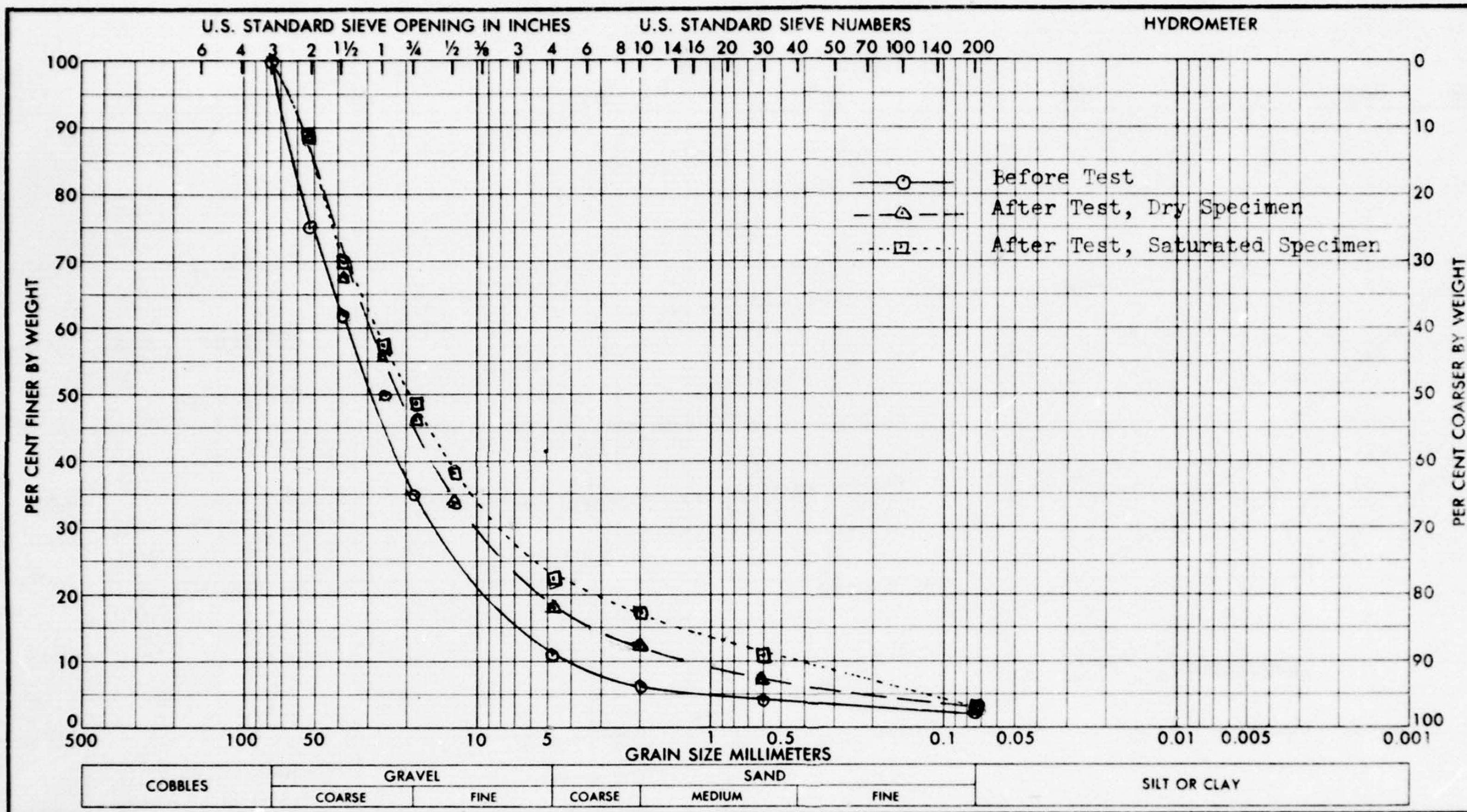


ES 526
SHEAR STRENGTH OF ROCK FILL
BUCHANAN DAM WEATHERED GRANITE
Natural Gradation
High Density
Initial Void Ratios
Unsaturated
Saturated
Void Ratio, e
0.44
0.42
0.40
0.38
0.36
0.34
0.32
0.30
0.28
0.26
15
30
60
120
250
600
800
Pressure, p, lb/sq in


K+E SEMI-LOGARITHMIC 359-71
KEUFFEL & ESSER CO. MADE IN U.S.A.
3 CYCLES X 70 DIVISIONS
Before Test:
Water Content, W_o 0%
Void Ratio, e .412
Saturation, S_o 0%
Dry Density, γ_d 118.9pcf
After Test:
Water Content, W_f 0%
Void Ratio, ef .307
Saturation, S_f 0%
Initial Void Ratio
UNSATURATED
Void Ratio, e
0.42
0.40
0.38
0.36
0.34
0.32
0.30
0.28
0.26
15
30
60
120
250
600
800
Pressure, p, lb/sq in
Specimen Diameter 12.0 inches
Specimen Height 9.99 inches
Specific Gravity 2.69
ES 526
SHEAR STRENGTH OF ROCK FILL
BUCHANAN DAM WEATHERED GRANITE
Natural Gradation
High Density
Consolidation



Initial Void Ratio
Before Test:
Water Content, W_o 0%
Void Ratio, e_o .422
Saturation, S_o 0%
Dry Density, γ_d 118.0pcf
After test:
Water Content, W_f 9.9%
Void Ratio, e_f .282
Saturation, S_f 94%
SATURATED
Void Ratio, e
0.42
0.40
0.38
0.36
0.34
0.32
0.30
0.28
0.26
15
30
60
120
250
600
800
Pressure, p, lb/sq in
Specimen Diameter 12.0 inches
Specimen Height 10.00 inches
Specific Gravity 2.69
ES 526
SHEAR STRENGTH OF ROCK FILL
BUCHANAN DAM WEATHERED GRANITE
Natural Gradation
High Density
Consolidation



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

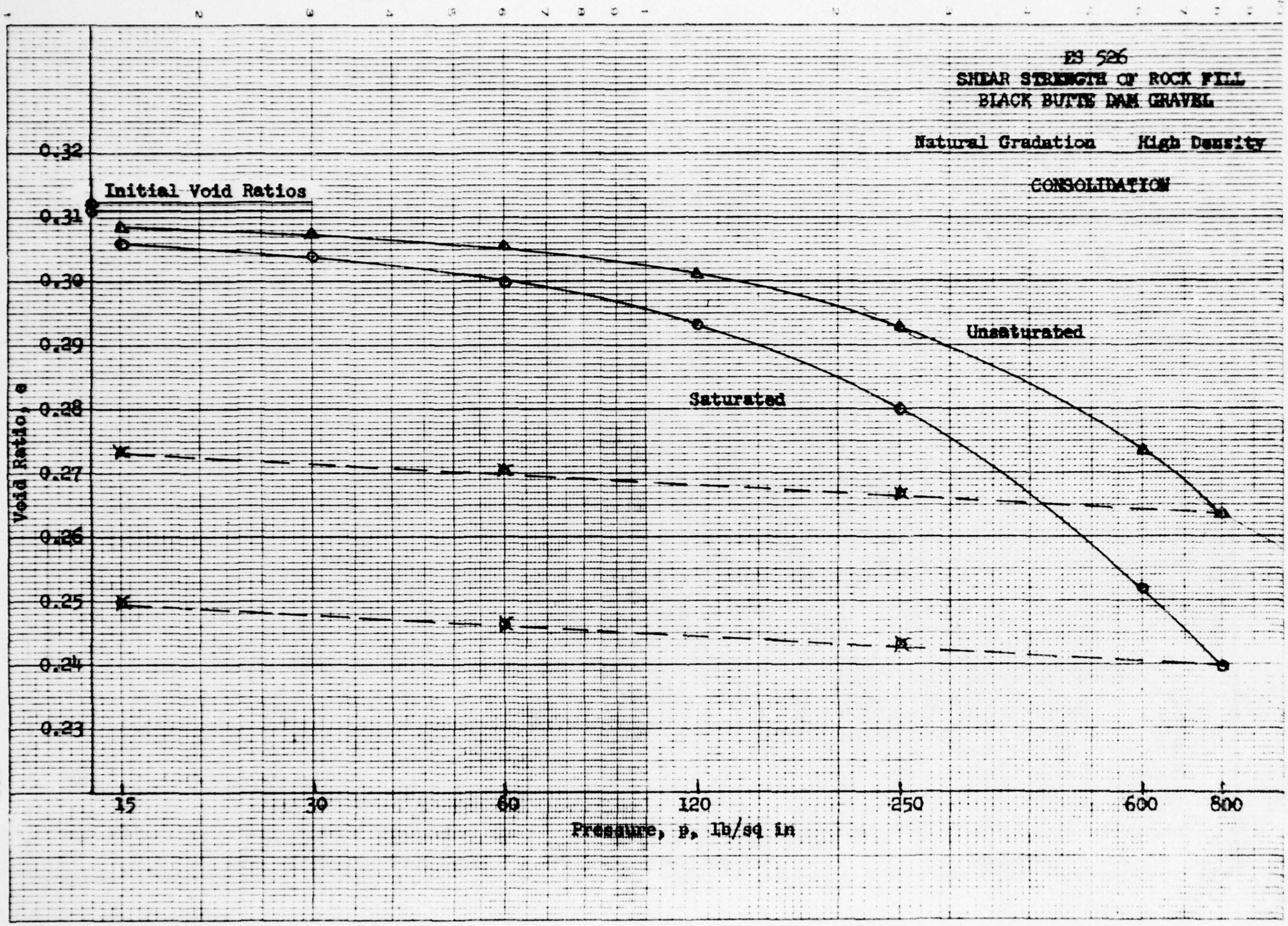
PROJECT	ES 526
SHEAR STRENGTH OF ROCK FILL	
AREA	Buchanan Dam Weathered Granite
BORING NO.	Natural Gradation
DATE	Consolidation

GRADATION CURVES

ENG FORM 2087
1 MAY 63

REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE. *(TRANSLUCENT)*

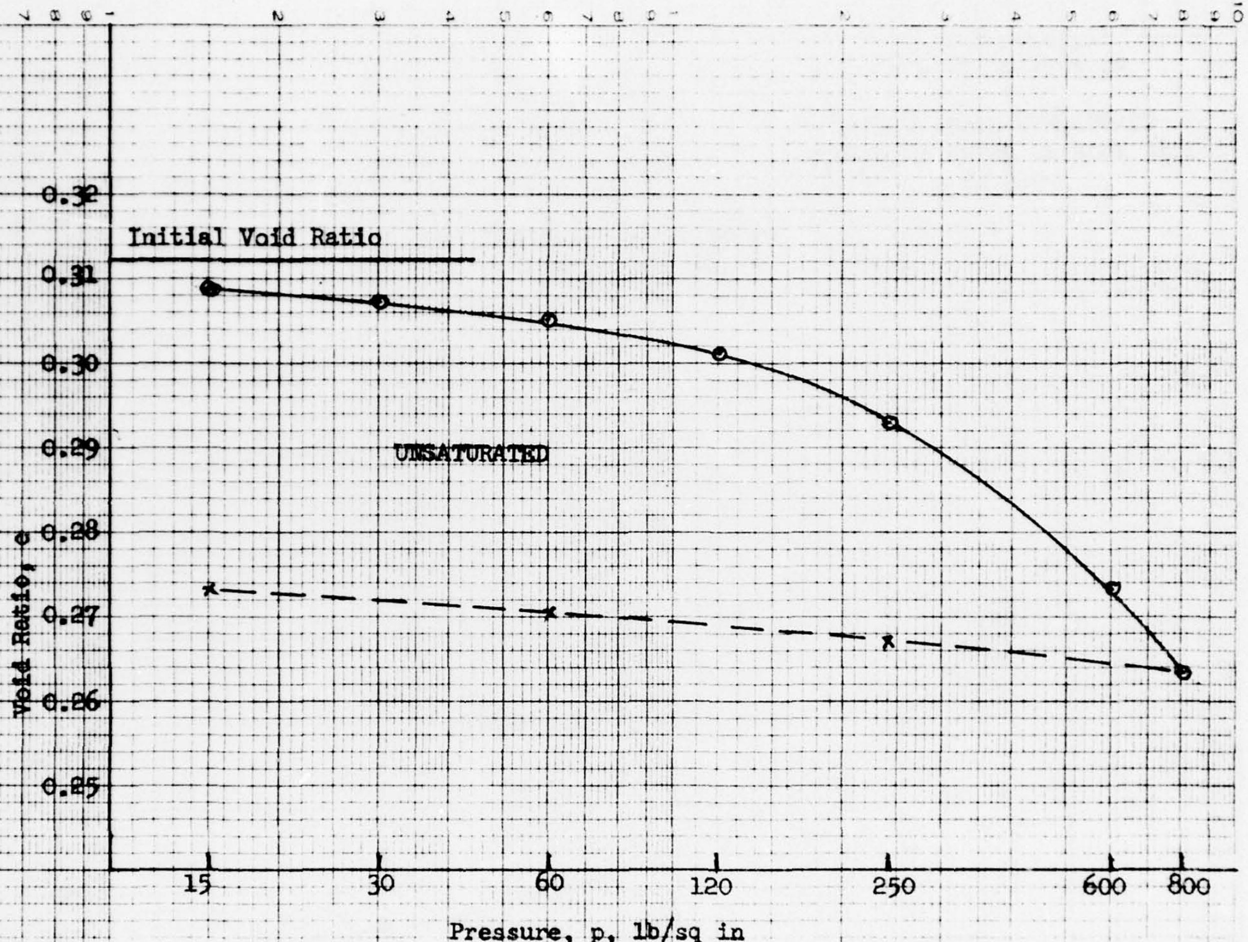
U.S. GOVERNMENT PRINTING OFFICE 1963 OF—709-126



ES 526
SHEAR STRENGTH OF ROCK FILL
BLACK BUTTE DAM GRAVEL
Natural Gradation High Density
CONSOLIDATION
Initial Void Ratios
Unsaturated
Saturated
Void Ratio, e
0.32
0.31
0.30
0.29
0.28
0.27
0.26
0.25
0.24
0.23
15
30
60
120
250
600
800
Pressure, p, lb/sq in

Before Test:
Water Content, W_o 0%
Void Ratio, e_o .312
Saturation, s_o 0%
Dry Density, 130.6pcf

After Test:
Water Content 0%
Void Ratio, e_f .278
Saturation, s_f 0%



Specimen Diameter 12.0 inches
Specimen Height 8.28 inches
Specific Gravity 2.75

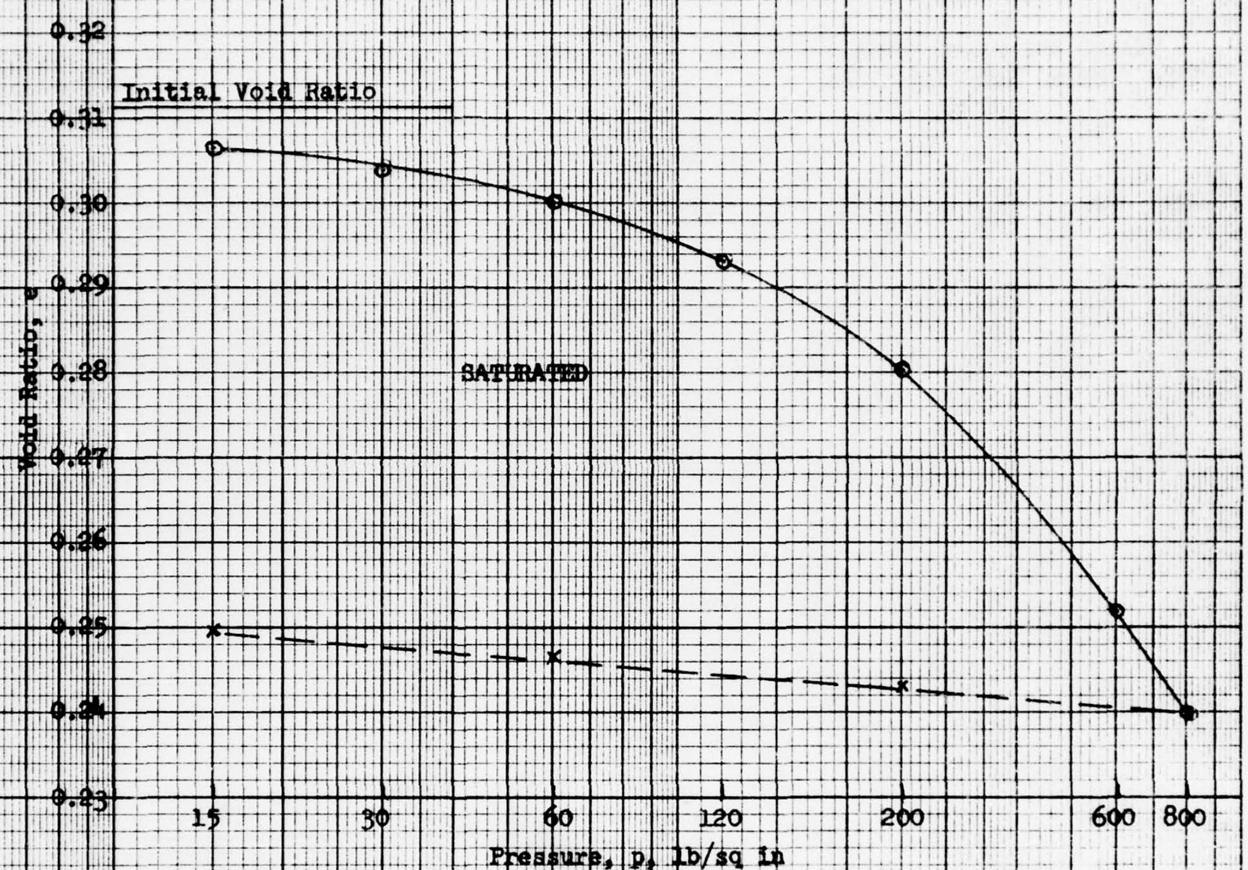
ES 526
SHEAR STRENGTH OF ROCK FILL
BLACK BUTTE DAM GRAVEL

Natural Gradation
High Density

CONSOLIDATION

Before Test:
- Water Content, W_o — 0%
- Void Ratio, e_o — .311
- Saturation, s_o — 0%
- Dry Density, — 130.9 pcf

After Test:
- Water Content, w_f — 9.2%
- Void Ratio, e_f — .254
- Saturation, s_f — 100%

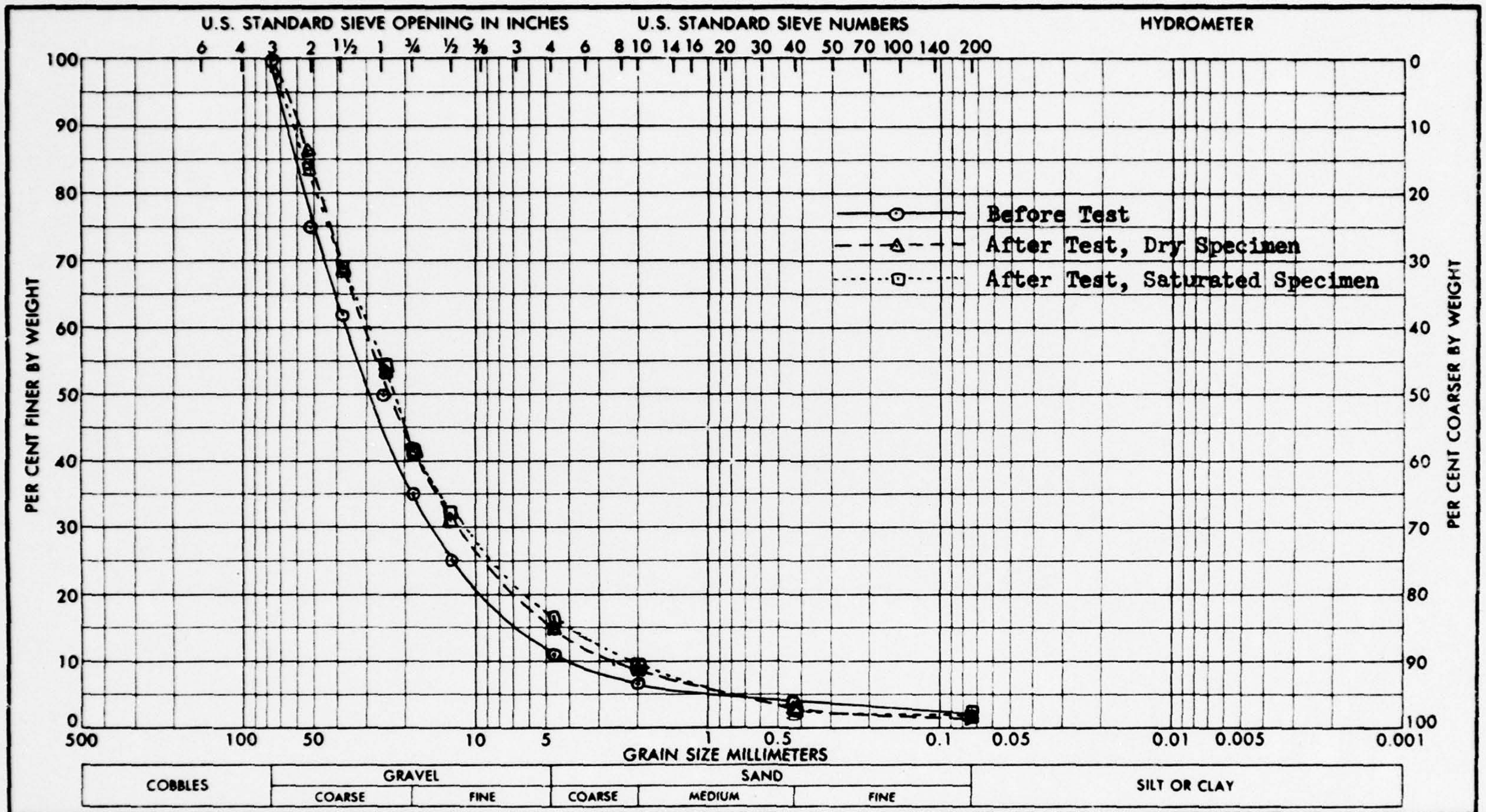


Specimen Diameter — 12.0 inches
Specimen Height — 8.28 inches
Specific Gravity — 2.75

ES 526
SHEAR STRENGTH OF ROCK FILL
BLACK BUTTE DAM GRAVEL

Natural Gradation
High Density

CONSOLIDATION



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

PROJECT ES 526

SHEAR STRENGTH OF ROCK FILL

AREA Black Butte Dam Gravel

BORING NO. Natural Gradation

DATE Consolidation

GRADATION CURVES

ENG FORM 1 MAY 63 2087 REPLACES WES FORM NO. 1241, SEP 1962, WHICH IS OBSOLETE.

U.S. GOVERNMENT PRINTING OFFICE 1963 OF—709-124

APPENDIX B

TESTING PROCEDURES

TRIAXIAL TEST APPARATUS

1. High Pressure 12-in. Diameter. This unit accomodates a specimen 12 in. in diameter by 27.7 inches high, which can be tested at a maximum chamber pressure of 500 psi. The testing machine is capable of producing an axial load of 200,000 pounds. Specimens are loaded axially through a 4-in. diameter piston terminating in an 8-in. diameter platen. The piston housing incorporates linear ball bushings and is sealed from the chamber by a teflon ring. Specimen is drained by a 3-in. diameter porous bronze plate set into the specimen cap and base. Drainage lines between the base and cap and the burettes mounted on the control panel consist of 3/8-in. nylon tubing with 3/8-in. ball valves and couplers. The specimen is connected to a 5-in. diameter lucite saturation reservoir and a 3500-ml. metal burette (plate B-1). Separation of the reservoir and burette is accomplished by a three-way valve. For seepage saturation, the bottom of the specimen was connected to the reservoir and the top of the specimen to the burette. During consolidation and shear, the top and bottom of the specimen are interconnected with this burette. The chamber fluid is linked to two burettes having a capacity of 3500-ml. each. To apply chamber pressure low-pressure air control was accomplished by means of a Norgren 125-psi bleed-type regulator. Chamber pressures were indicated on gages having ranges of 0 to 15, 60 and 150 psi. High chamber pressure was controlled by two needle valves and two metering valves with pressure indicated on 400- and 1000-psi test gages calibrated in divisions of 2 and 5 psi, respectively. There are two separate vacuum systems, each consisting of a vacuum pump, 15-psi vacuum gage, and a mercury switch for automatic control.

TRIAXIAL TESTING PROCEDURES

2. Preparation of Specimens. Four separate equal weight batches of air-dried soil were prepared for each specimen. For the high-density specimens, a rubber-lined 12-in. diameter mold was placed over the pedestal and membrane then secured to the triaxial base which was bolted to the Syntron VP-240 vibration table. Soil was placed in the mold with a scoop and positioned by hand. After two batches of soil were placed in the mold (first layer), a surcharge equal to 2 psi was placed on the soil surface and vibration started. Vibration continued for 8 to 10 min. with periodic observations taken to determine the height change. A second layer was placed and vibrated in the same manner. Low density specimens were also batched in four equal portions. Soil was placed in the same manner except that after the mold was filled with soil it was not vibrated. The cap was placed on the soil and sealed to the membrane.

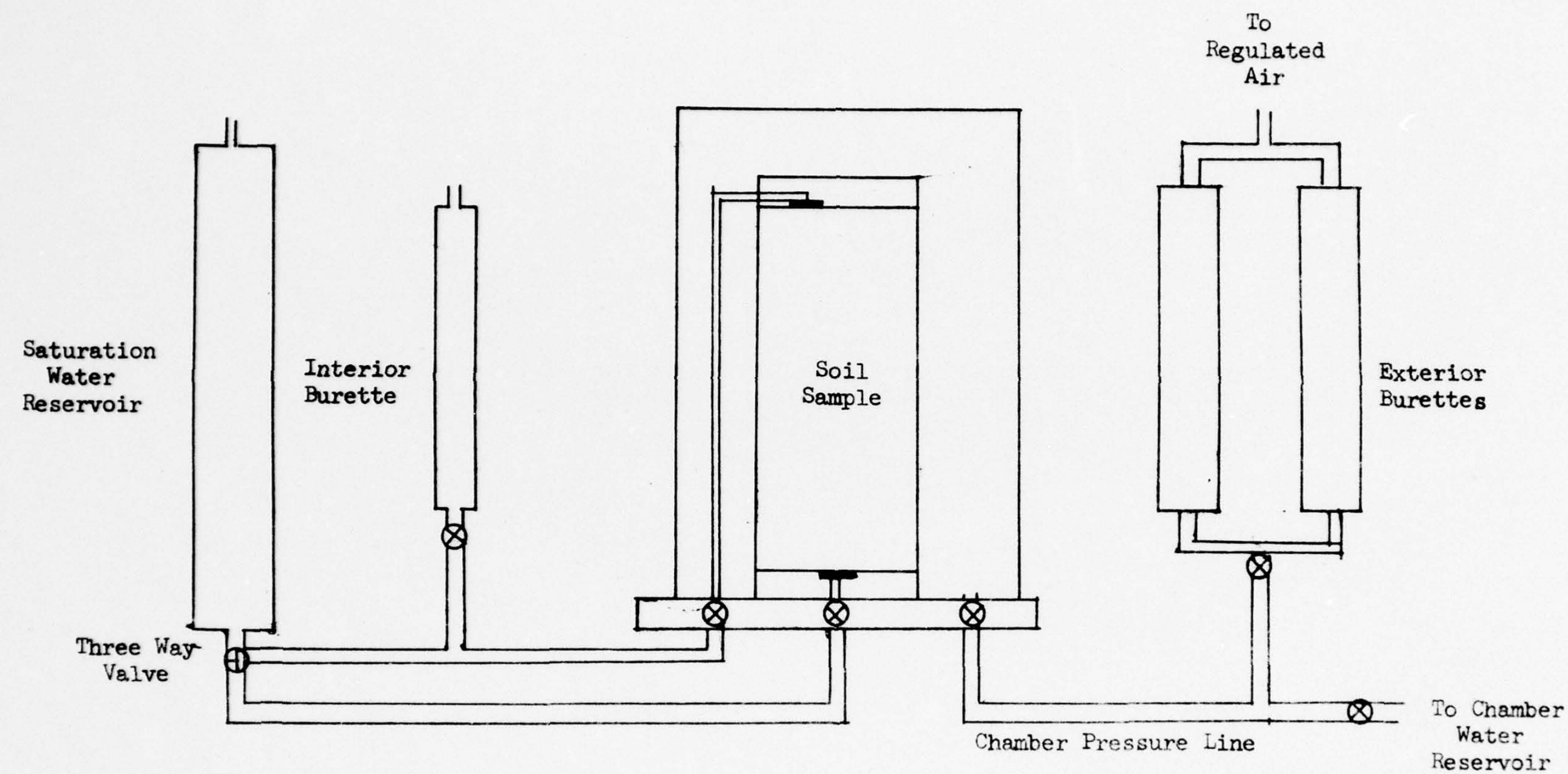
3. A vacuum of about 0.9 atmosphere was applied to the soil, the mold removed, and the height and circumference measured. A second membrane was placed over the specimen. Membrane thickness varied from 0.048 to 0.063 in. Specimens tested at lateral pressures of 300 and 400 psi had strips of 0.020-in. thick low-density polyethylene between the membranes. These strips were 2-1/8-in. wide and extended the full height of the specimens.

4. Saturation Procedure. After the apparatus was completely assembled and placed on the testing machine, the chamber was filled with water. Saturation was accomplished using deaired water by the seepage method using a differential vacuum. Initially, a vacuum of 14.5 psi was applied at the top of the specimen and 14.4 psi applied on the reservoir connected to the

bottom of the specimen, plate 1. This differential was gradually increased as needed to maintain a steady flow. Water was allowed to drain from the top of the specimen until the emergence of air ceased or became infrequent. This condition was usually attained when about 1500 to 2000 ml. of water had passed through the specimen. Saturation time varied from $1\frac{1}{2}$ to 3 hours. Height as well as volume changes, were noted during saturation. After saturation, the vacuum was slowly decreased and the chamber pressure correspondingly increased until a value of 15 psi was attained. This chamber pressure was maintained for not less than 2 hours, and in most instances overnight, before consolidating at the test pressure.

5. Isotropic Consolidation Procedure. In order to minimize the possibility of membrane punctures, the consolidating chamber pressures were applied slowly. The rate of pressure increase was about 30 psi per min. for specimens tested at 300 or 400 psi, but somewhat faster for the lower pressure specimens. After the application of the consolidating pressure, volume changes were recorded by the burette connected to both the top and bottom of the specimen. A check on volume change was by a burette connected to the chamber. Volume changes were noted until consolidation was complete. Generally, 30 to 60 minutes consolidation was required.

6. Compression Procedure. When the piston had been brought into contact with the specimen cap, the strain dial was read and the height of the specimen determined after correcting the dial reading for expansion due to chamber pressure apparatus expansion. Axial loading was applied at a



SCHEMATIC DIAGRAM
OF TRIAXIAL APPARATUS

Showing Drainage and Chamber Pressure Systems

FIG. B-1

B4A

strain rate of 0.25 percent per min. Constant rate of strain was maintained with the aid of a strain pacer. Readings were taken frequently during the first 10 minutes and at 3- to 4-min. intervals thereafter. The axial load dial, axial strain dial, interior and exterior burettes were read similtaneously. Axial loading continued until at least two time increments beyond the peak deviator stress. At the last reading, the valves connected to the top and bottom of the specimen was closed to maintain the water content and the vacuum that was induced when the load and chamber pressures were relieved. This is essential to prevent slumping of the sample while the apparatus is being moved from the testing machine and dismantled. After the apparatus had been dismantled, the entire specimen was oven-dried for at least 16 hours. Unit weight, moisture and gradation were then determined.

7. Shape Factor Test. Test sample quantities varied from 20 particles of the 3-inch sieve fraction to 500 particles of the $\frac{1}{2}$-inch sieve fraction. Particle sizes in this procedure refers to the passing sieve size. The volume of the sample was determined by: (1) soaking the rock in water overnight, (2) surface drying each particle, and (3) weighing the sample in air and in water. The particles were then counted and the average volume calculated by:

$$\bar{v} = \frac{(\text{Wt. in Air}) - (\text{Wt. in Water})}{\text{Number of Particles}}$$

The shape factor was calculated by:

$$r_v = \bar{v} \frac{6}{\pi d_r^3}$$

Where:

r_v = Shape Factor

$\bar{v}$ = Average Particle Volume

d_r = Passing Sieve Size

Values of r_v for each size were then used to determine a weighted average for the gravel portion of the sample.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)

(6) SHEAR STRENGTH OF ROCKFILL, PHYSICAL PROPERTIES.

Engineering Study Number 526.

5. TYPE OF REPORT & PERIOD COVERED

(9) Final rept.

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)

(10) Melvin W. Cohen
Dana D. Leslie

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS

South Pacific Division Laboratory, SPDED-GL
Post Office Box 37
Sausalito, CA 94965

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

ES 526
CWIS No. 31202

11. CONTROLLING OFFICE NAME AND ADDRESS

Office, Chief of Engineers, DAEN-CWE-S
Corps of Engineers, Dept of the Army
Washington, D.C. 20314

12. REPORT DATE

(11) Octo[redacted] 1975

13. NUMBER OF PAGES

136

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

(12) 138p.

15. SECURITY CLASS. (of this report)

Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Rockfill
Triaxial Compression Test
Consolidation Test
Abrasion Loss
Compressive Strength
Shape Factor
Scratch Hardness
Particle Breakage

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This is a report of the investigation of the relationship between physical properties and two engineering properties; shear strength and consolidation characteristics. Seven rockfill materials were tested using 12-inch diameter specimens with a maximum particle size of 3 or 2½ inches. There was good correlation of shear strength with abrasion loss, hardness, and compressive strength. Strength was proportional to compressive strength and hardness and inversely proportional to abrasion loss. There was good correlation of shape factor and compressive strength with volumetric and axial strain. Materials

DD FORM 1473, 1 JAN 73 — EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

410 326

20. (contd)
with high shape factor and compressive strength exhibited lower strain at failure. For consolidation, strain increased with increasing void ratio and decreasing compressive strength and shape factor. For all materials, greater strain occurred in the saturated than in the dry condition. Dry density was proportional to shape factor and specific gravity.